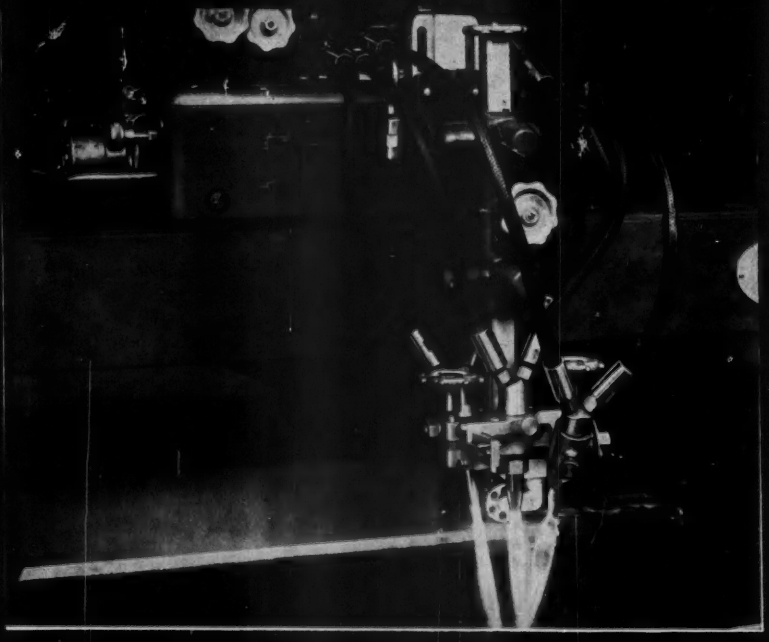

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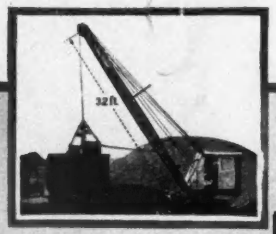

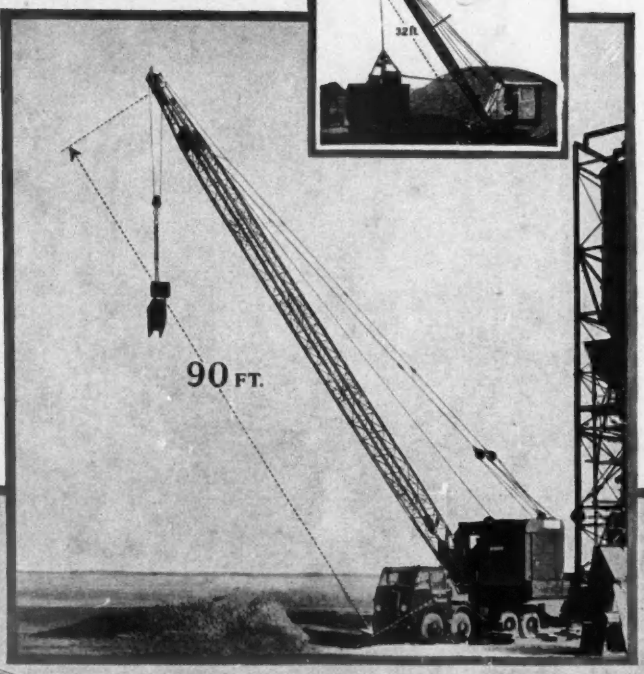

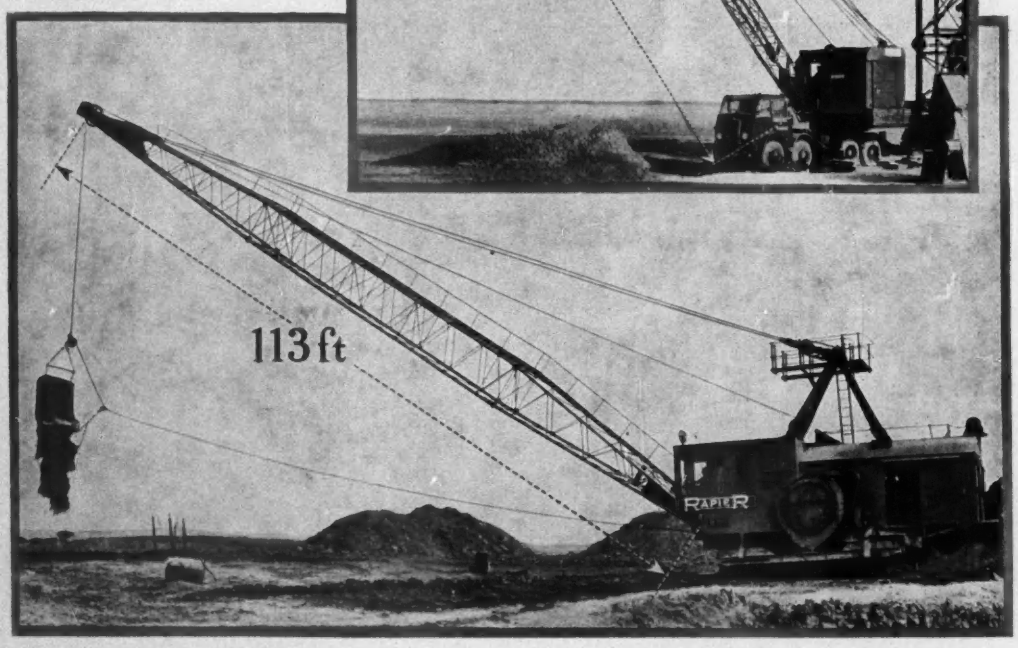

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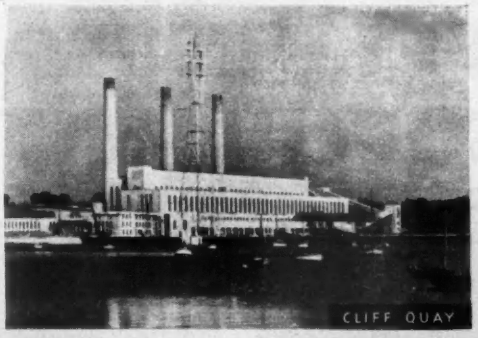

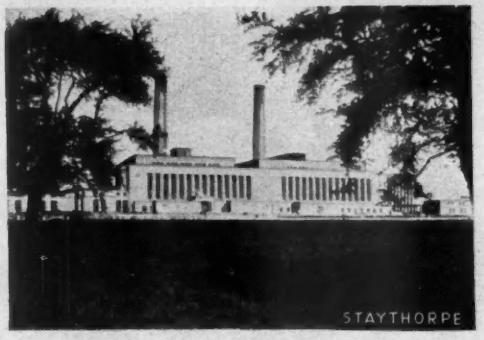

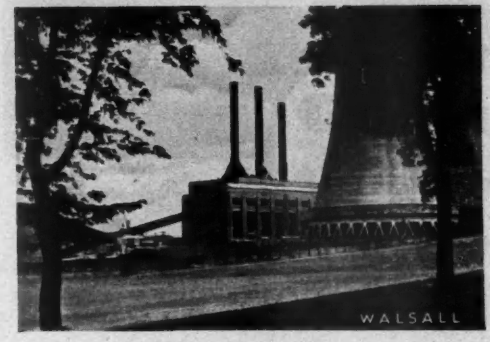

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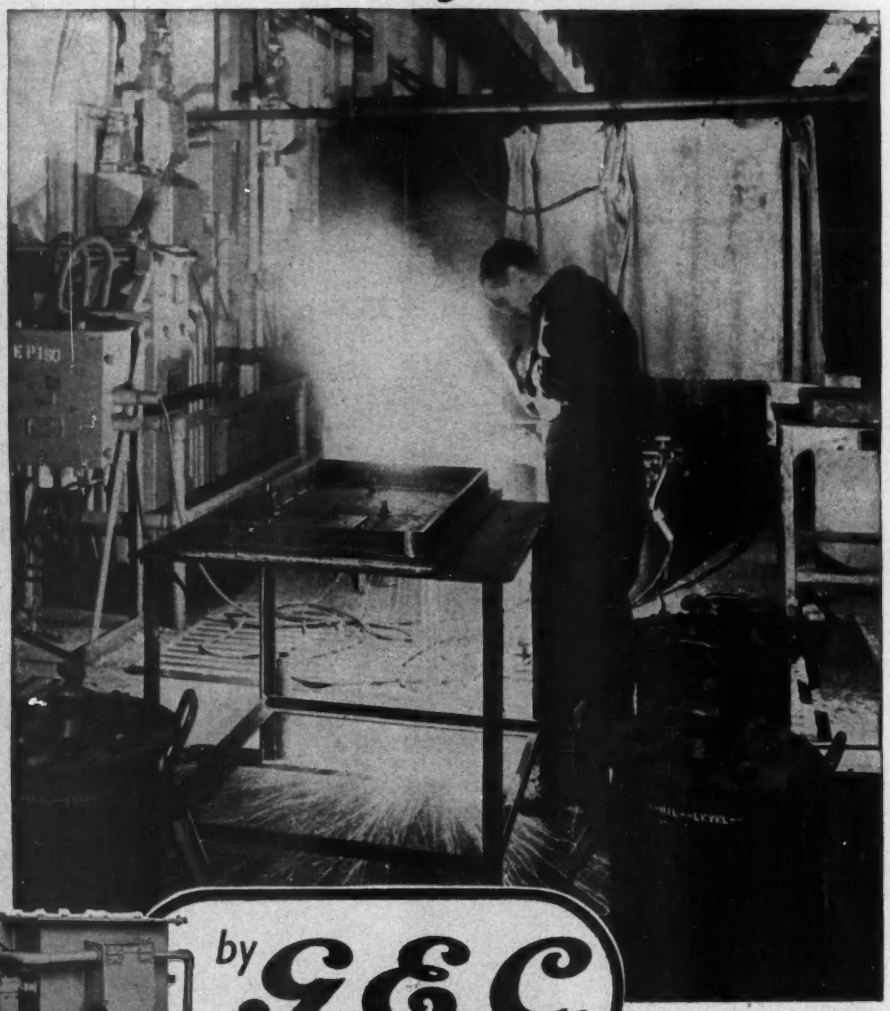

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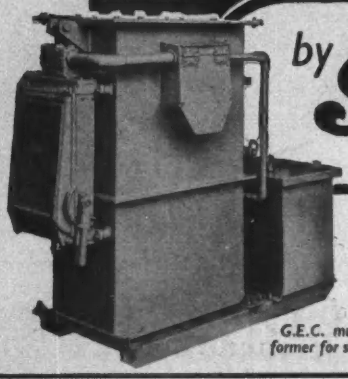

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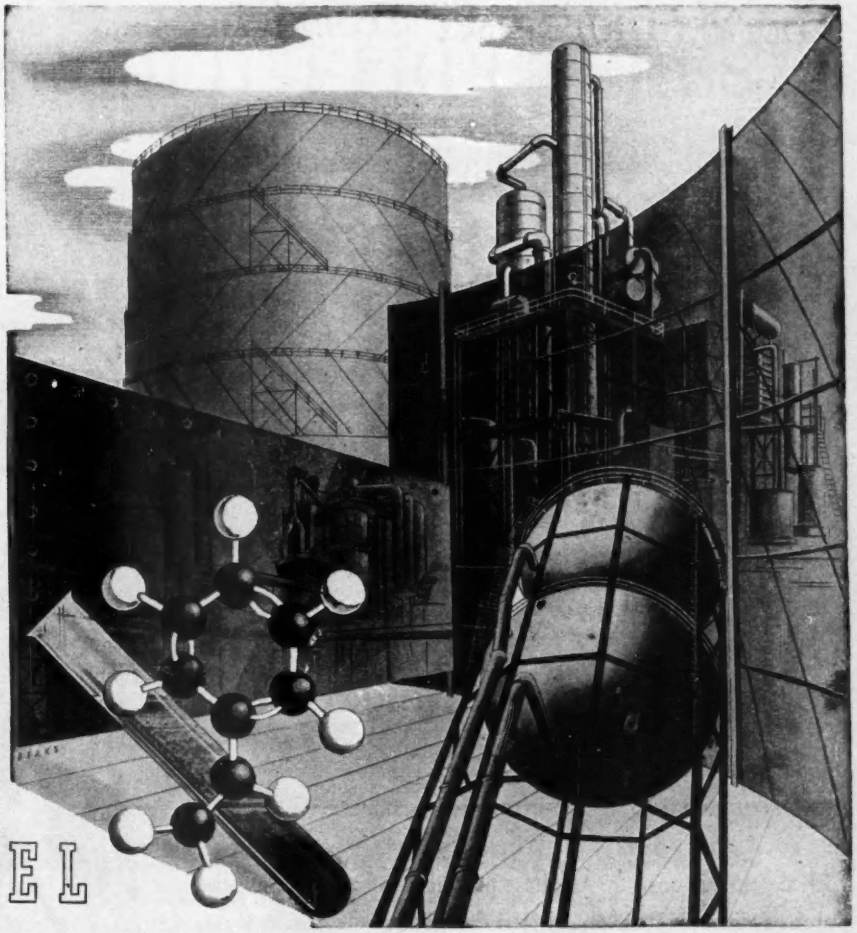

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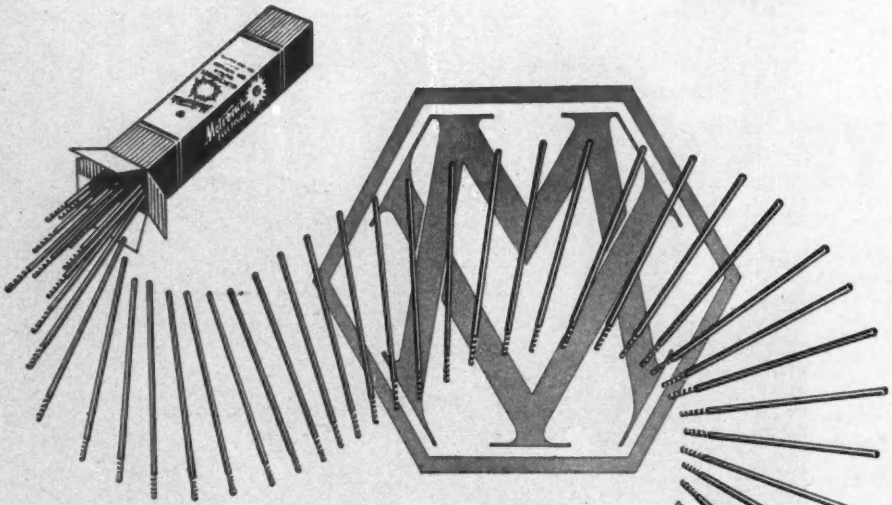

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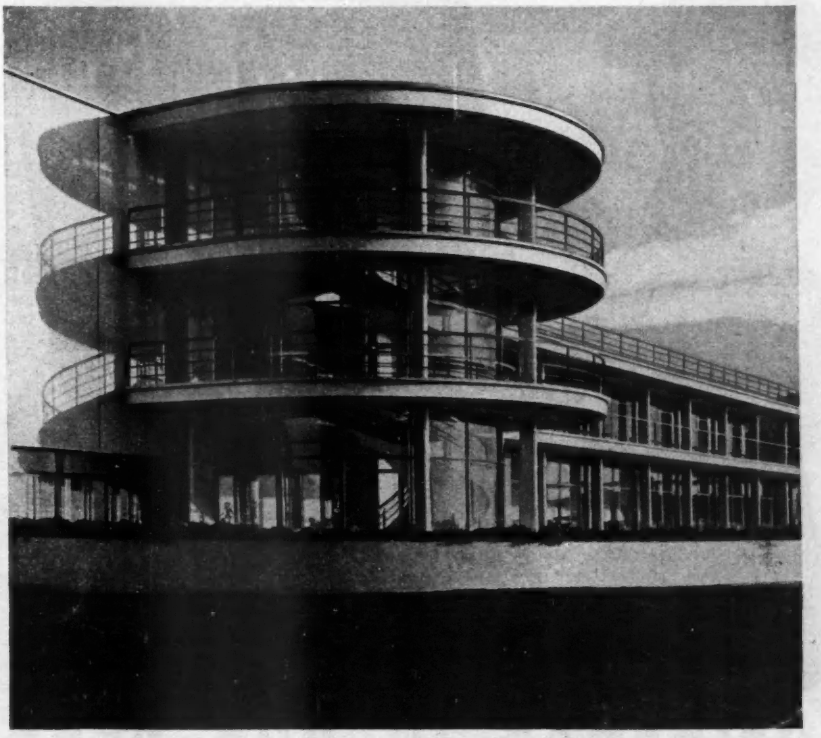

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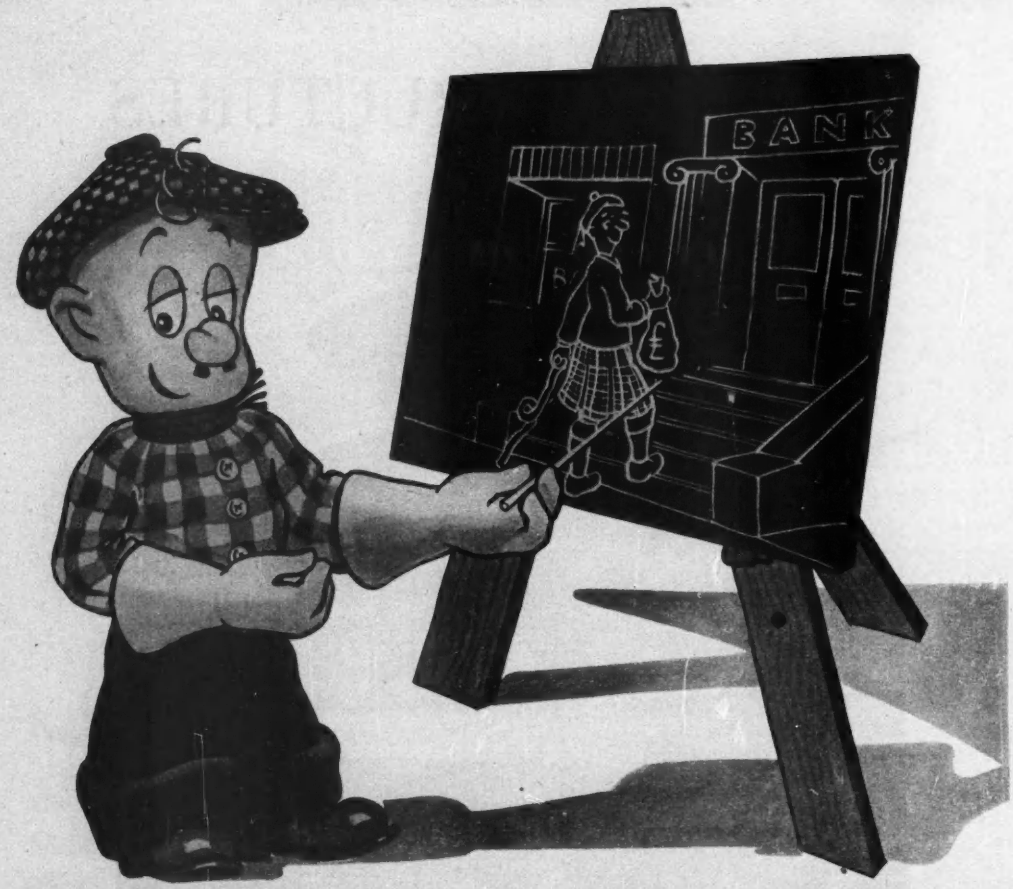

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Honorary Editor: D. S. WATT, B.Sc., M.I.N.A.

VOL. 13 No. 6 — DECEMBER, 1950 — PRICE 7s. 6d.

INSTITUTE NOTES AND NEWS

International Welding Congress.—The provisional programme for the International Welding Congress, which is to be held in London and Oxford from 14 to 21 July, 1951, was circulated to all members of the Institute early in November, with a reply form, for enrolment as a member of the Congress. The closing date for the return of these enrolment forms is 31 December; entries accepted after that date will require an enrolment fee of £1 instead of 10s., and this will not be repaid in the event of cancellation. Full particulars of the Congress will be sent only to those who have enrolled as members by returning this form, and it is, therefore, of importance that it should be returned by the prescribed date if possible. It should be emphasised that the return of the enrolment form does not bind anyone to go to the Congress, as the enrolment fee, if received before 31 December, will be returned to those who cancel before 28 February, 1951. The main purposes are to obtain a rough estimate of numbers, so that the necessary accommodation, transport and so forth may be reserved in good time, and to restrict the circulation of later circulars to those who will probably attend the Congress.

Appeal Liaison Officers.—In connection with the re-opening of the appeal for the working reserve fund, the Council has accepted a proposal of the Appeal Committee that Branches should be asked to appoint Appeal Liaison Officers. Their function will be to keep contact between the Branch Committees and the Appeal Committee and to bring the Institute's need of a working reserve fund before members in their Branch area, and especially Industrial Corporate Members.

The first of these officers to be appointed is Mr. C. H. Onions, past Chairman of the Wolverhampton Branch. We hope to be able to announce other appointments from time to time. Members will be able to obtain literature and other information about the appeal from the Liaison Officers.

Institute Luncheon.—The Institute's annual luncheon, held at the Café Royal, Regent Street, London, on Wednesday, 15 November, was well supported, nearly 130 members and guests being present. The President, Mr. C. S. Milne, was in the chair, and the guests were Professor E. Torroja, Sir William Stanier, Sir William Larke, K.B.E., Mr. N. M. Hunter, Mr. W. W. Watt, Mr. Howard Biers and Mr. J. E. Swindlehurst.

The toast of the Institute was proposed by Mr. Biers, one of the American representatives on the Council of the International Institute of Welding, who stressed the need for close co-operation between the British and American societies. Sir William Stanier, an Honorary Member of the Institute, replied to the toast and gave a most interesting brief account of the development of welding in its application to railway engineering within his own experience. The Chairman proposed the toast of the Guests, to which the President of the Institution of Structural Engineers, Mr. J. E. Swindlehurst, replied. Mr. Swindlehurst took up the point made by

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PRINCIPAL CONTENTS

Institute Notes and News	165
From Craft to Science	167
Welding in Germany	169
Working Reserve Fund	171
Latest Additions to the Library	174
Notes from the Branches	175
The Welding of Aluminium Alloys	178
Institute of Welding Meetings	186

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the Chairman, that structural engineers should pay more attention to the development of welding, by showing the close and continuous interest which his own Institution had had in it from very early days.

Welded Bridges in Spain.—The competition of two large institutional meetings in London on the same evening no doubt accounted for the comparatively small attendance at the meeting of the Institute on 15 November, when Professor E. Torroja, who had come from Spain at the invitation of the Institute, lectured on "Welded Bridges and Hangars in Spain." The lecture dealt in the main with bridges and other structures designed by the lecturer, and in particular those of composite construction, combining welded steelwork with reinforced concrete. We hope to print the paper, with a selection from the very interesting illustrations, in the near future, together with a summary of the discussion, which was particularly full and lively. The chair was taken by the President, who expressed the thanks of the Institute to Professor Torroja.

Plymouth Meeting.—The President of the Institute, Mr. C. S. Milne, was in the chair at a meeting held at Lockyer's Hotel, Plymouth, on 24 November last, when over 50 members and visitors heard a lecture on "Welding in Repair Work," with special reference to the motor trade, by Mr. A. Gilliard. The arrangements had been made by Mr. L. R. Preston, in consultation with other members of the committee of the former Plymouth Section, and the success of the evening encourages the hope that the Section may shortly be revived. Mr. Gilliard gave an excellently practical account of the procedure for all the common repair jobs on automobiles, illustrating his advice by blackboard sketches, and answered a large number of questions in the ensuing discussion, to which many contributors added useful suggestions based on their own experience.

A similar meeting is to be held at Exeter early in February next, when Mr. S. M. Algar will lecture on "Welding in the Maintenance of Agricultural Machinery."

New Seal.—At their last meeting the Council approved a new seal for the Institute and ordered the old one to be destroyed. This was necessitated by the change in the title of the Institute effected at the Extraordinary General Meeting on 25 January last, when the word "Limited" was dropped from the title. The new seal, which was designed by one of the Heralds, Mr. Anthony Wagner, incorporates the Institute's coat-of-arms, with the words, "The Common Seal of the Institute of Welding," in a surrounding band.

Abstracts in Transactions.—Readers will have noticed that the abstracts of welding literature, which are a valued feature of *Transactions*, have been missing from the last few issues. The reason is that Mr. Percival, who had very kindly supplied these abstracts for about a year, found himself unable to continue this service, and the Committees of the Institute concerned have been seeking a solution of the difficulty. We are glad to announce that a solution has now been found and that we hope to be able to resume publication of the abstracts early in the new year.

Specialist Team on Welding.—The Welding Productivity Team returned from the United States in the middle of November, so that its Chairman, Dr. H. G. Taylor, was just able to be present at the Institute's luncheon on the following day. All our readers will welcome the return of the team and will look forward to hearing what they have to tell us of welding in the United States, though it is not expected that the report, which they are to produce, will be available for distribution before next spring.

Reading of Papers.—Members of the Institute who would be prepared to read papers at meetings of the Institute or of its Branches are invited to forward the papers (or descriptive summaries) for consideration by the Programme and Journal Committee. Papers submitted in response to this invitation should reach the Secretary of the Institute not later than 9 March, 1951.

Handbook for Welded Structural Steelwork.—A revised reprint of the *Handbook for Welded Structural Steelwork*, which has been in the press for nearly two years, is at last available, price 10s. per copy, post free. The book incorporates a number of important corrections to the formulae on pages 111-118 of the fourth edition, but is otherwise identical with that edition. It is intended to circulate the corrections to the purchasers of the fourth edition.

Reprints.—Reprints of the following papers published in *Transactions* are available at the prices named:—R. G. Braithwaite and D. J. Davies, "Welding in Bridgework and Allied Structures"; paper, illustrations and discussion, reprinted from the December and February issues; price 2s. 6d. R. Weck, "An Account of M. Henri M. Schnadt's Ideas on the Strength of Materials and his Testing Methods"; reprinted from the April issue; price 2s.

Research Supplement.—With this issue of *Transactions* is included Volume 4, No. 4, of *Welding Research*, containing the following reports of the British Welding Research Association:—

R.63.—Tensile Properties of Mild Steel Weld Metal at High Temperatures by J. G. Ball and K. Winterton.

R.64.—Ductility of Mild Steel Welds near the Solidus by E. C. Rollason.

R.65.—An Explanation of Hot-Cracking of Mild Steel Welds by E. C. Rollason and D. F. T. Roberts.

Index to Transactions.—The index to the current volume 13, which ends with this issue, will be printed with the first issue of Volume 14 next February.

Binding of Transactions.—Arrangements have been made for the binding of members' volumes of *Transactions* in black embossed leathercloth at a cost of 10s. 6d. each, plus 1s. for postage and packing. Members wishing to take advantage of this arrangement should forward parts, with index, to Mansell (Bookbinders) Ltd., 31, Cursitor Street, Chancery Lane, London, E.C.4.

Examination Regulations.—Copies of the following document are available gratis to members on application to the Secretary of the Institute:—"Examination Regulations and Syllabuses."

British Standards.—We have been asked to draw the attention of members to the following British Standard which has now been published:—BS. 1501/6, 1950—Steels for use in the Chemical, Petroleum and Allied Industries.

Addendum to paper by J. F. Lancaster, B.Eng., on "The Argonarc Welding of Stainless Steel Sheet," vol. 13, No. 4, *August*, 1950.

Acknowledgements

The writer wishes to thank the Directors of The A.P.V. Co. Ltd., Wandsworth, London, S.W.18, for permission to publish the material included in this paper.

FROM CRAFT TO SCIENCE

WELDING OVER 40 YEARS

In his Presidential Address, delivered to the Institute on 25 October last, Mr. C. S. Milne defended the present requirements for corporate membership of the Institute by pressing the development of welding in this country during his lifetime. From his personal experience he showed how, beginning as a craft advanced by the trial and error of practical men, it had developed into a tool of numberless applications, relying upon the expert knowledge and experience of metallurgists, chemists, electrical and mechanical engineers.

We print below the text of the Address, with a selection from the extremely interesting series of slides shown at the conclusion of the Address.

THE events that took place at the last Annual General Meeting have influenced me in my choice of subject matter for my address.

Certain doubts were then expressed as to whether the Institute was developing along the right lines, which caused me to turn my mind back to the days when there was no body which had the interests of welding specifically at heart, also to ponder on the way in which this system of joining metals has become a necessity to every industry that uses metals.

I do not hold that in this imperfect world the ways in which the Institute is governed and members are admitted are necessarily incapable of any improvement, but I wish to make an earnest plea for consideration of the way in which the Institute has evolved over a period of years and the status it has already attained, before proposals are voiced that may possibly destroy that edifice.

One need only look at Europe to-day to see how easily even centuries of human endeavour can be destroyed, almost in the twinkling of an eye, when bad counsels prevail.

We are sometimes told that welding is in its infancy; if that be so, my observation of the diversity of the work done with its aid leads me to the conclusion that it is a remarkably healthy and well-developed infant and furthermore that the man who would really be the master of this precocious child to-day needs to be extraordinarily well equipped with scientific and technical knowledge; in addition to which he requires a great deal of experience of a practical kind in the vagaries of distortion and other matters which cannot be acquired from books.

As regards technical training it becomes year by year more difficult to set a limit to the range of studies which are necessary to the welding engineer, in a world where the number of ferrous and non-ferrous alloys which he may be called upon to unite increases almost daily. At the same time the codes of practice, systems of welding, both manual and machine, and the varieties of welding materials, such as electrodes and filler rods, multiply so rapidly, that the man who would carry out extensive manufacture of welded products needs more than a superficial knowledge of chemistry, metallurgy, electrical and mechanical engineering, together with what I may describe as a "low cunning" in the application of welding, both as regards design and procedure, which come only from practical experience.

Now welding may be only a process in manufacture, but it is a process that has such a wide field of application and is one that so profoundly affects the design of almost all engineering products, that we can surely claim that the welding engineer requires professional qualifications and that such men will, in an ever-increasing degree, be a necessity to industry.

If this is so, surely an Institute of Welding composed of men who will be recognised as possessing a high degree of scientific knowledge in matters appertaining to welding, simply because they are members of the Institute, must be an asset to industry and an inspiration to the younger generation who are training to bear the heat and burden of the day as the older generation fades out.

If my assumption is right it is surely incumbent on all of us to do everything in our power to increase the prestige of the Institute. In my view this can only be done if the system of intake of members is such as to ensure that the qualifications do not vary from one district to another. This necessitates the maintenance of central machinery for sifting these qualifications.

There have always been those who contend that any form of examination and particularly of written examination is not the perfect way of attaining this end, but no one appears yet to have produced any system which does not suffer from even more imperfections.

The young men who, under the present rules, have to take the examination, may feel a little hard done by when preparing for it, but they undoubtedly have a great and legitimate feeling of pride when they have passed the required standard, and I think it unlikely that those who have undergone this test will look with any favour on proposals to lower the standard in future. As regards those who have already reached a position of some responsibility in the welding world, they should surely be willing to undergo the self-discipline of writing an explanation of the whys and wherefores of some work they have designed, or which has been carried out under their supervision, in order to show that they have the requisite knowledge and experience to entitle them to membership.

We all know that so long as some of us older members are alive and active, who joined before any test of knowledge was called for, there will be certain anomalies, but it is wonderful how quickly time passes, and it will not be long before the majority of active members will be those whose qualifications have been scrutinised and who will feel a pride in the right to put M.Inst.W. after their names, and I believe that in an ever-increasing degree those who are looking for designers, works managers and welding engineers will come to recognise that these letters have a real significance.

Not the least of the anomalies is that I, who have no academic distinctions, should be defending the present membership rules, but I am not wearing too much sackcloth, as I feel that some of the acetylene generators and welding cutting equipment I have designed would enable me to write a report that might pass an even more stony hearted set of examiners than those of this Institute. I also take heart because I feel that my fellow-members would not have raised me to my present office unless I had done something for the advancement of welding.

Be that as it may, no one could be more sensible than I am of the honour you have done me in making me your President, and I would add that I am not blind to the fact that in scientific knowledge many of you have a far greater claim to high office than I have, so that the tale told of that great musician, Sir Edward Elgar, often comes to my mind.

The story runs that after listening to a fine rendering of Beethoven's Symphony in C, Sir Edward remarked: "When I hear that symphony I feel like a travelling tinker looking at the Forth Bridge."

I can assure you nothing could more concisely express my feelings when I see, or read of, the work of those giants of the engineering industry who design and fabricate such colossal welded structures as the Abbey Steel Works in South Wales, the gigantic dragline excavators used in winning open-cast coal, or the huge oil refinery vessels which from time to time pass through the London streets; while at the other end of the scale I am equally impressed by the skill, ingenuity and technical and metallurgical knowledge which go to the manufacture of such intricate devices as aeroplane jet engines.

The thought of the ever-expanding field in which welding is indispensable to modern industry leads me in turn to become reminiscent over the early days of welding.

Although I do not feel very old, I am sometimes shocked to realise that I remember a world in which the push-bike was just emerging from the "penny farthing"! a world completely devoid of motor cars, aeroplanes and fusion and other modern systems

of welding; things which those not so many years younger than myself found around them as they grew up and looked upon as an established part of our civilization.

I believe it is only fifty-two years since the first Arc Welding Company was formed in Sweden, and it was not until some years after that that any commercial interest in arc welding was evinced in this country. Oxy-acetylene welding was first practised in 1901, and in 1906 it was being exhibited at the Naval, Mercantile and Engineering and Machinery Exhibition by Messrs. Thorn & Hoddle, and was making considerable progress, probably because it seemed more conventional in those days to melt metals with a flame. I remember that at a similar exhibition at Olympia in 1910, organised by Mr. F. W. Bridges, the father of the present exhibition organiser, at least four firms were showing oxy-acetylene welding, and if my memory serves, no arc welding was on view. Two of those firms, the British Oxygen Co. Ltd., and Thorn & Hoddle Ltd., are still with us, while the others by a process of amalgamation have ceased to have separate entities.

My interest in that exhibition was that Imperial Light Ltd., by whom I was employed, were showing an acetylene generator for welding, for the design of which I was responsible. So it came about that the welding bug really bit me during this exhibition. The fourth firm showing was The Acetylene Illuminating Co. Ltd.

When serving my apprenticeship on the Taff Vale Railway in Cardiff, I had been impressed by the costliness of the repairs that could be necessitated by even a single leaky rivet in a boiler, and it appeared to me that an almost inhuman amount of skill was necessary to make tight seams at such places as the junction of the throat and wrapper plates with the barrel of a locomotive boiler. I had also noted the distressing way in which a patch plate on a cracked locomotive frame would shake loose, even though the bolts were a perfect driving fit when they were put in.

It appeared to me that in fusion welding we had the solution to all these problems, and so in 1911 I decided to start my own business and show the world how it should be done. Needless to say I soon found that it required more than my youthful enthusiasm to convince any large number of hard-headed engineers of the old school that there was anything in this new process. However, the firms who had already been pegging away at welding for some years were making steady progress and there was a constant accession of enthusiasts, so that the tide had begun to flow.

The British Arc Welding Co. Ltd. was already established, the Swedish Arc Welding Co. Ltd. started in business at almost the same time as myself, and the Quasi Arc Welding Co. Ltd., the Premier Electric Welding Co. Ltd. and others came into the field very shortly afterwards, but it was no easy matter to persuade people that there was anything to this new process of fusion welding. It was, they said, not welding at all; welding that could be trusted, they told us, was effected by hammering together two pieces of iron heated to a plastic condition. As for cast-iron welding, who had ever heard of anything so ridiculous! The idea was fantastic! Yet, when a casting fractured, or lap cracks and cracking between the rivets of a boiler seam occurred, which would entail a major repair, they could sometimes be persuaded to give these new welding processes a trial, and it may sound strange to some of you that oxy-acetylene welding was not infrequently employed in preference to arc welding on boiler repairs. I have some amusing memories of the rivalry that occurred when, as sometimes happened, my gas welders were working on one boiler of a ship and arc welders were employed on the other.

The Classification Societies and Boiler Insurance Companies soon found themselves on the horns of a dilemma. Here was a process that could save a lot of money in repair and replacements, but they were not convinced that it was a safe method to employ, so they proceeded with what some of us thought was undue caution, but was probably the wisdom of older men.

Taking it by and large, engineers were more conservative forty years ago than they are to-day and were in the main sceptical of these new-fangled notions, which cut right across all established practice. The engineering periodicals in their turn showed no great interest or enthusiasm about these new methods, consequently dissemination of knowledge of what could be done and of the best ways of doing it was meagre, and those who saw a future in fusion welding ploughed a lone furrow and had to feel their way individually.

Even in such matters as obtaining welding rods the manufacturer was not always helpful. Up to 1914 I had purchased cast-iron welding rods from France, and when the war cut off supplies, I almost had to go on my knees to Mr. Tibbenham, of the Suffolk Iron Foundry Co. Ltd. to persuade him to try his hand at producing some ferro-silicon rods. I am glad to know that he has had little reason to regret that he did allow himself to be persuaded to enter the welding field. Swedish iron was for many years the only wire that could be relied on to run satisfactorily. I remember on several occasions around 1911 approaching Rylands Ltd. for welding rods and being informed, in effect, that they had a very nice line in fencing wire but were not otherwise interested. It was therefore pleasant to find that the gnawing of the mouse was gradually severing the bonds of prejudice, when Sir Peter Rylands, as a convert to the value of fusion welding, became the first President of the Institution of Welding Engineers.

It is rather a sad reflection on the perversity of human nature that it was not the inherent merit of these new methods of joining metals that gave welding its first great surge forward, but the desire for self-preservation in the 1914-1918 war, since it was then found that the mass production of such war materials as floats for submarine nets and mine cases could be far more rapidly, and sometimes more cheaply, carried out by welding with semi-skilled labour than could similar rivetted equipment be manufactured.

I might mention that even in those early days the need for education in the welding field was realised and largely at the nstance of the late Mr. K. S. Murray, then managing director of the British Oxygen Co. Ltd., backed up by the British Acetylene Association, classes of instruction in the theory and practice of oxy-acetylene welding were started at the Northampton Polytechnic as early as 1912. In a paper which I myself read in 1920, before what had then become the British Acetylene and Welding Association, I stressed the need for knowledge of "design suitable for welding," and I well rememberthat Dr. J. H. Paterson, our last President but one, was a critical member of the audience on that occasion. I thought I knew all about welding then, but now I know I am only the tinker looking at the Forth Bridge. None the less I try to be a tinker with some vision.

At that time the only regular meetings dealing with welding were those of the British Acetylene and Welding Association, before whom Mr. Charles Hoddle had read a paper on the subject in February 1907. From 1918 until after this Institute was established the Association held frequent meetings which dealt with gas welding and cutting problems. Then in 1923 the Institution of Welding Engineers was formed to represent the interests of all systems of welding. This widened the sphere of interest and gave a platform for the rapidly developing art of welding, so that those entering the welding field from that time onwards had opportunities to put forward their views and discuss their welding problems with their fellows at the numerous meetings held by the Institution.

As engineers in general became more interested in the possibilities of welding, the magnitude and importance of welded structures and equipment increased rapidly and deeper scientific study became necessary to ensure the safety of many classes of welded fabrication. At this point the Institution of Welding Engineers was reconstituted as the Institution of Welding and took the bold step of inaugurating a Welding Research Council within the compass of the Institute, so that welding problems could be impartially investigated, thus the possibility of the development of welding being retarded by some serious accident involving great loss of life was forestalled. Later it became necessary, greatly to the sorrow of many of us, to separate the Research side from the Institute in order to retain the very considerable financial assistance given to research by the Government. This led to the formation of the British Welding Research Association, with whom, as you all know, the Institute of Welding retains very friendly relations.

Now my purpose in looking back over the years is to remind you that welding has progressed from a process in which the welder himself was the most knowledgeable man and in which

continued on page 173

WELDING IN GERMANY

EXHIBITION AT DUISBURG AND ASSOCIATION MEETING

Amongst the Technical visitors to the Duisburg Exhibition last June were Mr. Nicol Gross of the British Welding Research Association, Mr. J. L. Hancock of Messrs. Hancock & Co. (Engineers) Ltd., and Mr. R. R. Sillifant of The British Oxygen Co. Ltd. These gentlemen have kindly provided reports of their impressions of their visit and we give below a digest of them.

The Welding and Cutting Exhibition was opened on Saturday, 10th June, by the Mayor of Duisburg, and the President of the German Welding Association. At the same time business and technical meetings of the German Welding Association, held in the Hotel Duisburger Hof, were attended by between 500 and 600 members and visitors. Two days were devoted to technical lectures, and on the third day visits were arranged to a steel works and to an oxygen producing factory.

In his address the President of the German Welding Association, Prof. Dr. Ing. Dornen, regretted the backwardness of the German welding industry with regard to technical developments due mainly to the war and the intervening post-war period. Dr. Dornen stated, however, that the industry was returning rapidly to normal and that the German Welding Association and its members were ready and willing to play their part in international affairs in the welding field when called upon to do so.

Apparently the German welding industry is passing through a lean time, and it is suggested that the business available is not adequate to keep in existence no more than 50 electrode manufacturers, 100 gas welding plant producers, 100 arc welding plant makers and nearly 300 other firms producing accessories of all kinds. It is also mentioned that the position is aggravated by the loss of overseas markets and the dumping at low prices of electrodes and plant from Eastern Germany.

A programme of lectures was given in the Rhein-Ruhr-Halle which held 1,200 seats and was filled to capacity. The programme was as follows:—

A commentary on welding, by Dr. Ing. H. H. Grix and Dipl. Ing. C. Hase, entitled "A Review of Welding Technology."

"Ten Years of Welding Progress in U.S.A.," by Kinzel, Swan and Biers, read by Mr. Howard Biers.

"Developments in Welding Technology in Western Europe," by Dr. C. G. Keel.

"The Weldability of Constructional Steels," by Dr. Ing. H. Buchholtz.

"Weldability Problems of Low Alloy Steels, with special reference to the Schnadt Test," by Ober Ing. Bjorn Kjellberg.

"Gas Welding in Boiler Construction," by Dipl. Ing. Rugel.

"A.C. Arc Welding with Symmetrical Three-Phase Loading," by Dipl. Ing. R. Hofmann.

"Powder Cutting," by Dipl.Ing. Pfeiffer.

"Recent Problems of Gas Welding Technique," by Dr. Ing. E. Zorn.

"The M.H. Welding Process," by Karl Meller.

"The Welding of Plastics," by Over Ing. P. Voigt.

Most of these papers were reviews of the present state of knowledge regarding the main problems encountered in welding, and the only item which appears to be worthy of mention here is the M.H. Welding Process. This process consists essentially of a method of increasing the deposition rate in electric welding by using two electrodes simultaneously in the same weld puddle by means of a gravity device which allows one electrode to be used automatically, whilst a second is deposited in the same puddle manually. This proposal, however, is not considered to have very great novelty.

The Welding and Cutting Exhibition itself covered a very large area and was very well attended.

In general, the exhibition showed that the German welding industry is very alive and conscious of the need for up-to-date and efficient apparatus. For example, all of the firms in this field had exhibits of regulators, blowpipes, hand-cutters and accessory devices in a great variety of forms and types. The larger firms, such as Messer, Linde, Werk Grieshein, Muller, Lorch, etc., all exhibited their standard lines of blowpipes and cutters, and a number of the smaller firms, such as Lambert Fell and Otto Lieberknecht exhibited principally blowpipes of various types and advertised their readiness to carry out repairs on all types of oxy-acetylene equipment.

In general, it may be said that there were few, if any, novel items amongst these, but Messer showed several large blowpipes for heating, flame hardening and other applications. On the Muller stand was seen an oxygen cutter of otherwise standard construction, but with a cutting oxygen valve of the plug cock type, worked by a lever, very similar to the controls of a Fletcher gas-air blowpipe. All of the big firms exhibited both gas welding and electric welding equipment and the Linde stand featured, of course, the German counterpart of Unionmelt, i.e. the "Ellira" process, and in this connection a very novel prototype automatic hand welder.

In the accessories field, some six or seven firms showed generators of various types and capacities, the most outstanding being one on the Muller stand in which the gas generation was kept in step with consumption without, it is claimed, after-gassing, by means of a high-pressure, carbide-to-water type of generator. It is made in five sizes, from 50 to 1,000 kg. carbide capacity, delivering 7,000 to 80,000 litres per hour (i.e. 245 to 2,800 cub. ft. per hour approximately). Control of the generator is accomplished by means of a water motor which is actuated by the water level.

In the flame-hardening field the Peddinghams Company exhibited a great variety of burners and blowpipes of various types, and in one instance a number of slit burners, in widths up to approximately 4 in., were shown, particularly for the spin hardening of gear teeth. The firm specialises in machines for the use of oxy-coal gas only, and uses no other fuel gas. Some of the specialised flame-hardening machines on show for the treatment of small details were interesting and ingenious.

On the stand of the German branch of Arcos Ltd., Aachen, a novel type of electrode, the so-called "folded" electrode, was exhibited.

It is produced from steel-strip (or strips of other metals) which are folded repeatedly, flux and metallic additions in powder form filling the cavities as provided. This electrode is used for arc welding, but also as filler rod for gas welding copper and aluminium, where it has the advantage that no separate flux is required. A detailed description of the "folded" electrode can be found in *Die technische Linie*, No. 11, of the 3rd June, 1950. Amongst the many types of electrodes marketed by Arcos there is a hydrogen-controlled electrode. A usual requirement for these electrodes is the quench-bend test in which the test pieces are heated to 600 deg. C. and quenched to 28 deg. C., after which they are bent round a former having a diameter equal to three times the thickness.

Many types of resistance welding machines were exhibited

including an automatic spot welder for lap welding sheets. The machine had a pair of electrodes giving two spot welds simultaneously, the electrodes being fed along automatically after each weld.

The Rheinische Rohrenwerke Mulheim-Ruhr, makers of large diameter pipes and pressure vessels exhibited in addition to pipe bends, arc and gas-welded X-pieces, super heater elements and similar products, a special fabricated sleeper for drag-line rails for brown coal open-cast mining. In their application of the submerged arc welding method for large wall-thicknesses, they use as an alternative to multi-layer welding, the so-called tandem-welding, by means of which two runs are deposited in one pass, thus allowing a better control of the crystallisation during cooling.

The exhibits in the open part of the Exhibition served to show how widely welding was being applied to the fabrication of engineering structures, and the exhibit of the German Railways was very interesting in this connection, in that a welded passenger coach, a welded underframe for a goods wagon, and a completely welded goods wagon were on show, together with a welded locomotive boiler, cylinder chest, and similar items.

One particularly interesting exhibit was a fabricated column which was illustrated in the welded as well as in the riveted form, and an interesting comparison was drawn to show the savings which can be effected in the construction of an item such as this by welding.

The Krupp works exhibited a fully welded locomotive frame and locomotive boiler, one interesting feature of which was the use of a special section for the tube plate.

While the German technical press has often published valuable papers showing that the developments in non-destructive testing methods are closely followed (see for instance "Non-Destructive Testing of Welds," by O. Vaupel, in *"Schweissen and Schneiden,"* No. 6, 1950), there was no evidence of interest in this field at the Exhibition. The only testing equipment exhibited were two X-ray units made by Siemens and Seiffert. No other methods were discussed nor was apparatus shown.

The only evidence of research into welding problems was a stand describing an investigation connected with argon arc welding at the Technical University in Aachen.

This report would not be complete without mention of the high standard of the German Technical Press concerned with welding. Its main exponent, the monthly *Schweissen und Schneiden*, edited by Professor H. Koch of the Technical University in Hanover, has contributed in no small measure to the success of the Exhibition.

THE START OF THE "I WEES"

Mr. Lane's Recollections

Among those who accepted the President's invitation to the luncheon on 15 November last was Mr. T. V. Lane, one of the Honorary Members of the Institute. Mr. Lane was, unfortunately, prevented by illness from attending, but sent the draft of a speech, in which he outlined the steps leading to the foundation of the Institute in 1923.

We print below some extracts from this draft, which we think will be of particular interest to some of our older members, who can recall the welding "situation" at the end of the war of 1914-18, when Mr. Lane, discharged from the army on medical grounds in 1917, had returned to his pre-war employers, Messrs. Ryland Bros. Mr. Lane's recollections are interesting reading in conjunction with Mr. Milne's Presidential Address in this issue, and with the sketch of the Institute's history in the Silver Jubilee number (February, 1948).

"One day the late Sir Peter Rylands wanted carbide for Lady Rylands' car lighting. It was essential, as she was a keen worker among our wounded men and did much to help them and the hospitals in which they were being treated. While waiting to get my permit, I overheard a conversation. One of our old oxy-acetylene welding friends was being put off and was told he should adopt electric welding! Thus was started the rumour that electric welding was only a 'war-time substitute.' This was my introduction to the industry, and I soon made it my business to look over this new 'find.' Wire was essential. It was greedily consumed and tons were required. Swedish charcoal iron, previously used by the oxy-acetylene welders, was unobtainable. Mild steel might be a substitute. If my employers could produce, there was a big field—a new one—and permits were readily and gladly given. I haunted welding shops all over London to learn how the work was done. Mines, aircraft and other war-time requirements demanded the best welding wire. Thus I had to find the big distributors of oxygen, acetylene, and so on. Looking in the directory I started alphabetically, and thus found my old welding friends of to-day, one or two of whom introduced me to the British Acetylene and Welding Association.

"Previously, this Association had been entirely interested in carbide and acetylene, but with the advance of welding they included welding—*oxy-acetylene* welding! The Association was at times financially embarrassed and the 'hat' was passed round. I objected and urged the admission of the electric arc people. I became a nuisance and was eventually invited on the Council—to gag me, I guess—but I still pointed out (as I thought) the way to solvency and a much bigger Association. I have since realised that I was acting very foolishly, as in the interests of the B.A.W.A. welding was only a secondary consideration, and even then, only the oxy-acetylene process. To-day this Association is once again the British Acetylene Association, and I am very happy to know that it is housed with the Institute of Welding in Buckingham Palace Gardens. I made it my policy to get to know the people running trade papers, and so far as the welding industry was concerned, I approached the Editor of *The Acetylene and Welding Journal*. The editor and owner, the late Mr. Charles Raggett, had kept in step with the B.A.W.A. When the Association was known as 'The British Acetylene Association,' Mr. Raggett's journal was *The Acetylene Journal*; with the change to B.A.*W*.A., it changed its title to *The Acetylene and Welding Journal*. This was no use to me in my efforts to get the gas and electric people together. It took some time to induce Mr. Raggett to take the plunge, i.e. to drop the word 'Acetylene' and give the welding industry its "Welding Journal." The venture was successful; the previous oxy-acetylene advertisers did not drop out and the electric people came along with new revenue. Thus we had a neutral journal to back up my suggestion of an association interested in *all* systems of welding. I may claim that I was the back-room boy and No. 1 member of the I.W.E. If I had not inspired Mr. Raggett, another would have done so, but, without conceit, I may add that I cannot recall any of our early friends who could claim to be strictly neutral. I was in the happy position of being able to say, 'I am not interested in any welding process except those which demand welding wire,' and as both oxy-acetylene and electric arc were greedy consumers, I loved both equally and only desired to do a spot of welding myself—to weld the oxy-acetylene and the electric arc folk together in one scientific association. Mr. Raggett called the first meeting and eventually 'The Institution of Welding Engineers' came into being. Looking back, I cannot understand why the word 'Engineers' appeared. The title was put to the vote, and we became 'The I.W.E.'s' (I.Wees). Then the fun began! I was free to call on all interested in welding (never mind the process), and Mr. Raggett did the secretarial work, unpaid. He also provided the office accommodation—again buckshee. Thank you, Mr Raggett! Oh! how we fixed the 'papers'! The balance had to be maintained, one electric, the next oxy-acetylene, a neutral one on 'Steel' and so on. I attended all evening meetings to entice new members. Eventually the work became too heavy for our unpaid secretary, and we engaged the part-time services of Mr. Raggett's clerk. It cost us £2 per week, a terrible risk, but we managed until the next big headache—renting our own office, with a full-time secretary and a typist. Again we found the finance: we had our own first registered office in Holborn Town Hall. The 'I.W.E.' was at last established."

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R. D. Berry, A. Buchan, G. A. Burnham, W. Linsay Burns, M. P. Henzell, H. Hutchison, J. C. Mackain, H. R. McKinstry, F. A. Manders, E. R. Roberts, J. Stoddart, D. D. Taylor, D. W. Wright, R. M. Young.

Leeds Branch

C. Allinson, R. Archer, J. H. Arnold, J. H. Atkinson, T. H. M. Backhouse, H. Buckle, R. Coley, W. B. Coulson-Smith, G. Crowe, G. E. Curran, F. Curtis, R. Davies, E. Davy, R. H. Evans, R. Gardener, H. S. Gardner, J. Grimmer, R. Hargreaves, J. T. Harrison, A. Harrop, T. Humes, A. Hunter, A. Kinder, T. W. Loftus, H. Maudsley, C. Middleton, W. Nicholls, C. E. Rhodes, J. Rhodes, A. S. Rymer, R. C. P. Shoesmith, A. Sills, H. R. Smith, W. Stock, W. Swan, W. Swire, R. Sykes, A. E. Wilson, G. N. Wilson, R. Woodward.

Liverpool Branch

J. A. Abrams, A. Bailey, A. S. Bartlett, R. E. Bowles, J. H. Burton, R. R. Butler, J. Cahm, D. W. Campbell, P. Carlson, A. F. Coulson, B. C. Couturier, H. R. Cox, A. W. Cunliffe, G. Davenport, J. R. Dodd, J. Done, M. Donnelly, E. Y. Felton, E. Ford, E. J.

Gittens, J. E. Griffiths, G. G. Heys, S. L. Holt, H. H. Hughes, T. Hughes, E. Johnson, D. G. Jones, A. Lamb, E. S. Lea, W. Lee, R. G. McLacklan, J. K. Maddick, W. T. Matthews, L. J. Metcalfe, M. L. Meyer, R. L. Newton, J. T. Nulty, W. Oakes, L. H. Oakley, M. Price, G. A. Pridgeon, J. L. Stephenson, G. H. Taylor, R. Taylor, E. Thomas, A. G. Tregaskis, R. Trevethan, D. T. Turner, T. Tushingham, R. W. Wainwright, W. Wallace, G. Woodfield, E. E. Wright.

Manchester Branch

G. F. Armfield, J. Ashworth, G. Bagley, H. Banks, A. Berry, A. Birks, G. Bowness, M. K. Bryce, C. W. E. Cary, R. L. Collins, H. Condon, F. Darbyshire, A. Deakin, A. Dixon, V. Dougall, R. H. Elston, T. Evans, I. C. Fitch, S. Fitch, E. A. Foreman, H. Foxton, A. H. Fryer, E. Fuchs, H. St. G. Gardner, A. E. Goodbury, J. A. Griffin, A. K. Grimshaw, A. E. V. Grosvenor, F. Hampson, E. S. Hancock, S. M. Hawken, F. Hollows, A. E. Holt, G. A. Jibson, E. W. Jones, S. H. Jones, W. Jones, W. Kinghorn, H. E. Krikken, R. T. Lamb, R. Lord, F. J. McCann, W. L. McIvor, J. B. G. Martin, L. H. Morgan, S. Morris, J. H. Normand, H. M. Odgers, J. S. Owen, J. Quarmby, G. Ribchester, J. L. Robinson, R. Robinson, A. L. Shacklock, J. Shaw, F. Smith, H. M. Smith, W. J. Stringer, W. Sutherland, A. R. Taylor, F. W. Taylor, J. H. Todd, M. G. E. Wade, D. M. Walkden, S. Walker, F. E. Waring, W. M. Watson, C. W. Whitehurst, G. Whiteside, J. Williams, W. Wood, A. E. Wright.

North London Branch

S. A. Adams, E. J. Ashton, W. A. Austin, C. H. Bacon, D. A. Ball, G. K. C. Balmer, T. F. Barnes, P. C. Beckett, W. A. Belverstone, R. S. Binnie, C. F. Bird, R. Bishop, R. Blacksley, C. G. Blaker, K. M. Blauhorn, H. P. Bowler, G. E. Brabrook, C. H. Braddle, F. J. Brand, F. Brauer, C. W. Brett, W. Broadhead, L. Brooks, R. E. Broom, G. Brown, H. C. Brown, N. D. Brown, R. G. Brumby, R. J. C. Bryce, C. Bugge, W. C. Burgess, S. W. Burman, E. L. Burrill, C. A. Burton, D. W. E. Butterworth, S. Byer, H. G. Cale, C. E. Campbell, J. S. Campbell, E. T. Casey, E. R. E. Catchpole, N. B. Cave, E. R. Chamberlain, G. F. Charge, S. W. F. Chittleboro, F. Clark, G. H. Clark, M. T. Clark, A. J. Clarke, M. Clarke, O. Cobb, A. D. Colledge, E. J. Cook, P. A. Cook, E. C. Corbett, A. H. Coules, C. Coulson-Smith, H. J. Crussell, R. G. Cubbage, G. Davies, R. P. Davis, C. H. Davy, N. V. Dinning, P. T. Dobson, R. E. Dore, B. E. Dorey, V. R. Drake, R. Drucker, A. L. Dugay, J. B. Dunbar, F. M. Easton, R. Edwards, C. W. Ellender, J. H. Evans, W. Evans, W. H. Evans, A. A. Eyers, A. C. Farge, A. J. Ficken, L. Fish, L. G. Ford, W. French, F. J. Gale, R. J. Gardener, F. E. Garland, Sir Alexander Gibb, G.B.E. C.B., J. Y. Gibb, Dr. H. Gottfeldt, G. L. Greaves, W. Griffin, C. Griffiths, H. Grist, C. G. Guess, D. Hagan, J. M. Haig, C. G. Hales, M. B. Haley, J. P. K. Hamilton, F. Hamshaw, A. Hardy, L. C. Harris, W. E. Harriss, J. R. Hart, A. Hartley, R. S. Haward, H. Heath, C. W. Hill, A. J. Hoare, L. H. Hockney, E. J. Holding, A. Holmes, H. G. Hooper, F. D. Hucklesby, A. Hunter, F. Irvine, T. W. Irwin, W. M. Jackson, A. Knowles, C. F. Lamb, G. A. Lane, Sir William J. Larke, K.B.E., J. I. Law-Brooks, I. Levin, L. J. Lewis, N. L. G. Lingwood, C. F. O. Lister, B. C. Little, M. H. Lummus, E. McMinn, J. H. Maidment, T. A. Malone, F. H. Marriage, G. Mattock, E. J. Maul, C. A. Messetter, H. J. Metcalf, G. A. Morris, G. W. Morgan, D. T. J. Moss, G. H. C. Moss, H. Parr, C. G. E. Parrott, W. M. Pearce, P. W. Pell, H. N. Pemberton, L. C. Percival, A. J. Pilbin, W. A. Pinnock, N. C. Porter, G. A. Pratt, S. T. L. Prior, G. W. Pybus, W. E. Quine, A. E. T. Reed, A. E. G. Rice, G. W. Rigby, A. T. Roberts, M. Roche, W. A. Roy, J. R. Rudman, W. S. Ruff, E. Ryalls, J. E. Sanson, C. A. Sayer, W. R. Scott, F. A. Sharp, R. B. Shepheard, W. J. Sibley, D. L. Sidney, R. R. Sillifant, S. F. Silsbury, B. W. Silverwood, D. Simmons, E. J. Sims, C. E. Slade, F. Sleigh, A. A. Smith, E. J. Smith, L. B. Smith, F. S. Snow, J. Stafford, G. G. Stark, A. Stephenson, R. J. Stewart-Jones, F. J. Stiles, G. A. K. Stobie, P. F. T. Street, Dr. H. G. Taylor, F. R. L. Tilling, A. Tomlinson, W. T. Towler, W. R. Travers, J. Turnbull, W. B. Turner, W. A. Tyrrell, J. P. Ullmer, W. L. Upton, F. P. Vickers, H. A. Vickers, A. E. Villiers, E. S. Waddington, L. Wallace, K. Ward, F. G. Warner, W. Watson, W. J. West, R. C. Westbrook, T. P. G. Whitley, J. H. Widdecombe, H. G. S. Wilkins, A. T. W. Williams, C. H. J. Williams, E. M. Wilson, J. A. Woods, R. F. Worcester, R. J. Wright, R. V. Young.

Portsmouth Branch

R. Anscomb, F. A. Betts, J. Campbell, W. T. Farmer, A. C. Hart, H. Kendall, W. T. P. Kirkham, C. C. Lavington, A. A. Lockyer, L. P. McCorkell, N. C. Parsons, A. S. R. Saunders, E. G. Smith, L. R. Stubbington, A. Sykes, R. G. Taylor, A. E. Tidman, H. C. Townsend.

Sheffield Branch

W. S. Acaster, T. F. Archer, R. Blackburn, R. E. Booth, C. W. Bower, R. E. J. Burgess, H. Colledge, B. Cowlishaw, E. Crapper, J. E. Crooks, C. G. Fleetwood, J. Gilling, F. Goy, H. Harvey, J. W. Hayes, W. Hill, J. D. Holtby, W. A. Jenkins, H. M. Lebrecht, W. Lees, R. W. Littlewood, A. K. Matthews, L. Mellor, E. F. Mitchell, A. D. Pates, A. F. Pates, A. Richardson, F. E. Rowley, E. H. Rycroft, K. N. Selby, H. G. Sissons, A. W. Stones, J. H. Stubbings, W. Swallow, S. Teale, T. Tolworthy, H. W. Toseland, A. Townend, H. Townend, H. F. Tremlett, A. West, A. J. White, A. L. Williams.

Southampton Branch

J. P. Bedford, G. W. Blanchard, J. Brogden, P. W. Carter, A. H. Coster, P. Fielden, S. L. Harnett, F. A. Hill, H. W. Kenyon, C. E. Leatherdale, C. E. T. Mullins, C. J. Parsons, A. H. Penn, P. Quihampton, W. R. Spilman, A. Wickings, W. G. Young.

South London Branch

L. L. Arundel, K. J. Austin, W. J. Ayley, F. W. Balkwill, H. I. Barclay, S. A. Barkshire, A. J. V. Beaumont, H. Beesley, F. Bennett, S. D. Bing, A. G. W. Bingham, J. R. Blower, O. Bondy, P. H. Boyden, W. Bryant, D. K. Buckle, E. F. Burford, R. G. Burt, S. F. Busby, R. C. Bush, T. L. H. Butterfield, R. A. Cameron, V. W. Clack, E. J. Clark, E. C. T. Coombes, W. G. Cossentine, F. C. C. Cullum, H. W. Davey, C. E. Durant, R. J. Eagles, E. M. Elen, A. J. Elliott, J. I. Faulkner, S. G. Ferns, H. A. Fitch, C. A. Flack, W. A. Fletcher, J. A. Forgione, V. A. Fox, K. P. Gan, C. B. Garwood, A. A. Gillies, Sir Stanley V. Goodall, K.C.B., O.B.E., A. L. Haggerty, F. E. Halls, R. G. Harrison, R. J. Harvey, I. H. V. Hayes, C. C. Henderson, A. E. Hill, W. L. Hinton, L. E. Hoddle, W. F. Hope, F. S. Houlston, F. G. Hughes, J. A. Hullett, E. S. Humphries, D. E. Hursey, R. A. Iddon, A. V. Ivitsky, W. D. Jobson, H. C. Johncey, W. G. Jones, W. Keeling, W. C. Keen, R. King, C. A. Ladd, E. Ladd, G. L. Lane, S. G. Lane, S. G. P. de Lange, A. MacKechnie, S. McNeil, A. G. Manktelow, E. J. Marsh, W. K. B. Marshall, F. W. Martin, J. A. Matthews, J. Mills, C. S. Milne, W. A. Mitchell, A. R. Moss, P. Murrell, R. K. Musted, A. F. B. Nall, D. E. Nash, J. E. Oliver, E. G. Osborne, F. B. Ottway, B. Parker, W. Parry, J. Percy, A. Pickering, H. L. Pritchard, W. H. T. Pullen, R. W. Schofield, B. Scruby, J. F. Seale, Dr. R. Seligman, J. G. Shelley, F. C. Skinner, F. W. Slatter, A. E. Smith, J. D. Smithers, L. E. Snapes, E. L. Speight, W. Stephens, F. Stott, J. B. Summerhill, H. W. Taylor, R. H. Townsend, J. H. Tyler, G. W. H. Vincent, W. C. Walker, A. F. Warner, R. R. Waters, F. J. Webster, A. J. Wills, H. E. Wood.

South Wales Branch

P. C. G. Andrews, M. C. Blackley, C. M. Cable, F. Camm, G. W. Cragg, R. A. Cragg, E. Davies, K. J. Eaton, F. E. Emery, G. A. Evans, B. B. Gaydon, T. Griffiths, T. A. Herbert, A. V. Hooker, G. C. Jones, R. A. Jones, W. T. Jones, H. W. Kimpton, R. Lloyd, A. W. Lovering, J. D. MacGregor, J. Noakes, B. O'Neill, H. E. Pendree, R. E. Phillips, A. Postance, H. Price, G. Samuel, G. H. Thomas, W. A. Tyrell, J. Webber-Singer, S. F. Woolway.

South-Western Branch

S. H. Baker, W. L. Brook, W. J. Burdett, T. Burgess, C. C. Evans, F. J. Fearn, E. R. Fellows, I. B. Ford, H. J. Fortune, A. Gilliard, C. F. Gregory, S. J. Ham, J. Hathway, R. M. Hawkins, W. R. Hill L. C. Hippolite, C. G. Hoddinott, R. T. Howes, S. R. R. Johns, A. V. Joines, J. Lawrence, H. C. Lee, G. G. Marshall, W. H. Y. Masters, J. A. Moray, R. S. Morse, W. G. Mumby, E. C. Palmer, W. H. Payne, A. W. Pinnell, A. V. Player, L. R. Preston, H. G. Price, A. V. Puddle, L. E. Rees, B. R. E. Riddaway, E. B. Robinson, J. M. Rome, R. V. Rowles, W. P. Sanford, W. A. Scott, R. O. J. Taylor, G. H. Turnbull, A. W. Wall, H. Williams, C. T. Wilson, W. L. Wilson.

Tees-side Branch

J. T. Barber, O. Barrett, F. G. Batchelor, G. Boyd, J. H. Carter, E. G. Clark, S. Clark, H. Clarke, R. G. Crowe, D. E. M. Flavell, J. H. Harrison, J. W. Jackson, W. Jeffrey, W. Merchant, S. North, J. N. Parkin, W. Ramsey, Lt.-Col. S. B. Roberts, R. Robinson, T. W. Sanders, P. Scarth, W. P. Seymour, W. Shepherd, J. G. H. Varley, J. W. Weir, F. S. Wilson, S. Walker.

Tyneside Branch

W. Angus. T. W. Appleby, A. C. Ashton, W. E. Baker, J. G. Barker, F. Bell, J. Birkett, H. Bond, F. D. Carr, N. Daniel, R. Dean, J. W. Dickson, E. Elsworth, R. A. Exton, E. R. Fryer, J. Gerrard, A. Gibson, T. S. Glasper, J. N. Green, C. W. F. Hann, W. Hannon, G. R. Head, J. C. Lloyd, K. Maddison, F. Medcalfe, A. H. Minnikin, A. A. J. Mitchell, W. Muckle, W. Nunn, W. Pickering, P. L. Pocock, R. A. M. Porter, J. C. Riddle, J. L. Robb, A. Robertson, H. F. Sanderson, J. B. Smith, C. Stephenson, W. H. Stubbs, J. M. Thompson, R. S. Tron, W. R. Waite, E. B. Watkin, W. J. Wroath.

West of Scotland Branch

A. Adam, J. L. Adam, H. Anderson, J. M. Anderson, A. E. Attwell, E. A. G. Ayling, R. H. Bannister, M. S. Barclay, J. M. Baxter, G. W. Bell, J. M. Binnie, W. Bone, J. Boyd, R. M. Brackenridge, P. Buchan, J. Cameron, W. K. Carey, V. H. Carty, J. Clark, J. Cranson, J. A. Cuthbertson, J. Duncan, J. Gilchrist, H. J. H. Gould, W. Heigh, J. H. Hunt, D. Hutton, W. Kennedy, D. Kilpatrick, J. Liddel, D. W. Low, T. Lyons, A. Mair, J. McBurnie, Sir Andrew McCance, R. A. McDonald, R. McEwan, J. G. McGregor, J. J. Macklin, G. S. McTaggart, A. Munn, J. Murray, J. C. S. Payne, M. W. Pearce, W. Philip, E. A. Rex, S. C. Rogers, T. S. Ruthven, A. M. Shaw, J. L. Stevenson, J. G. C. Thom, J. Webb, R. Whyte, M. Wilkinson.

Wolverhampton Branch

R. W. Allan, H. H. Allen, J. Askin, A. H. Bent, I. A. Biggs, D. D. Bradley, J. A. Brough, V. A. Burrows, Roland Butler, A. J. T. Clements, J. Dennis, G. A. Dews, L. C. Dipper, R. D. Edwards, W. Evans, D. Ewan, E. Fellows, A. B. Fieldhouse, E. Flintham, W. Foster, G. R. H. Garlick, J. H. Gilmore, S. H. Griffiths, A. Q. Hartill, A. Hawley, N. Holland, L. Horton, F. Hotchkiss, H. Scott Jeffs, F. Jukes, E. M. Kitson, E. J. Mitchell, J. A. Morton, G. G. Musted, E. R. Nichols, G. Nicklin, C. G. Owen, L. Palmer, G. E. Richards, A. L. Roberts, T. G. Robson, K. A. Roche, J. Sleath, S. G. Smith, C. Spencer, W. H. Stevens, J. Strong, A. H. B. Swan, J. T. Tatchell, C. E. Taylor, F. Thomas, J. R. Thomas, A. G. Thompson, H. J. Thompson, J. H. N. Thompson, T. H. Thornton, E. H. Vincent, K. G. Walker, S. C. Walker, G. H. Ward, A. C. White, P. F. Wilks, F. E. Willets, W. A. Wrate.

Overseas and Unattached

A. Arnold, D. Bailey, D. T. Barks, R. G. Barrow, W. K. Bettesworth, H. Brickwood, W. B. Brown, O. V. S. Bulleid, B. R. Byrne, H. K. Cheesman, A. J. Claassens, C. G. Clarke, E. Crowe, T. C. Court, J. Davies, J. F. Davies, W. Davies, C. R. Deglon, R. Ducklin, T. Fairhurst, C. Fishback, Dr. C. Gloor, R. M. Gooderham, S. Gurney, D. E. Hamm, J. W. Hammond, G. Harden, E. Hardwick, S. F. Hillsdon, J. B. Hogarth, D. Hotchkiss, L. F. Jacobs, L. James, A. N. Jeffery, R. V. Jones, J. Koziarski, K. Kunjithapatham, F. H. G. Lane, W. H. Langford, A. R. Lawson, R. A. Lee, A. M. Lovatt, N. McGrath, K. K. Madsen, F. A. Martin, Dr. L. Matteoli, W. C. Millar, T. Milne, E. D. W. Mitchell, C. Nielsen, F. F. Newton, Capt. J. R. Nortier, G. Parkes, G. R. W. Pocock, E. Le Poidevin, G. Porter, M. S. M. Rashad, A. P. Rickard, H. R. Rose, T. R. Shields, C. W. Snell, G. Sturley, M. Supertino, W. F. Thurland, D. F. Vissenga, R. N. Walton, I. Willson.

FROM CRAFT TO SCIENCE—*continued from page* 168

hit-and-miss methods were employed, to a science in which the Welding Engineer and Designer with technical and scientific knowledge has become one of the most important people in the set up of modern industry, and I contend that this Institute has played a prominent part in this process of evolution.

In inaugurating a Welding Research Association this Institute undoubtedly did a great work for British industry. Now it can continue the good work by maintaining the status of membership at a level that will be universally recognised by industry as a hall mark of the member's knowledge of his subject, instead of once more lowering the standard, as is proposed in some quarters.

I submit that with this Institute, as with others, maintenance of a high standard can only be achieved by examination, or, as I have already said, in the case of those of more mature years, by asking them to give evidence of their knowledge and experience in writing, and I hope our members will point out to those who boggle at the idea of spending valuable time in putting pen to paper, that if the Institute is to be of value to them in an increasingly scientific world, membership is worth this sacrifice of time and labour.

To the younger members I would say: when you join any organisation, whether it be a business, a football club or an institution, don't worry too much about what you are going to get out of it; your worry should be how much you can put into it. I was given that advice by the late Mr. Alexander Jackson the manager of Carbic Ltd., soon after I got interested in welding, and over a considerable number of years I have found that if one makes that one's philosophy, one gets a lot more fun out of life than those who sit and wait for others to empty the cornucopia of plenty into their laps.

In conclusion I would suggest that in addition to supplying a forum for discussion, a library, a journal and other minor services, one of the great benefits of an Institute such as this is the opportunities it affords its members for making friends who will help them over stiles, for there can be very few members who are not willing to give the benefit of their experience to another member who has got caught up in the toils of some awkward welding problem.

Latest Additions to the Library

AS a supplement to the Library catalogue, this section of the *Transactions* contains particulars of books and pamphlets added to the Library during the last quarter of the year. The books, pamphlets and periodicals specified are available on loan to members of the Institute.

Publications preceded by an asterisk are donations to the Library from authors or publishers; those preceded by a dagger are donated by the James F. Lincoln Arc Welding Foundation.

BOOKS AND PAMPHLETS

***ALUMINIUM DEVELOPMENT ASSOCIATION**

Proceedings at a symposium on aluminium in road transport, 14th February, 1950. Illus. 1950. Publishers: Aluminium Development Association, 33, Grosvenor Street, London, W.1.

***ASSOCIATION OF HEATING, VENTILATING AND DOMESTIC ENGINEERING EMPLOYERS**

Year book of the heating and ventilating industry. Illus. 1950. Publishers: Technitrade Journals Ltd., Carlisle House, 8, Southampton Row, London, W.C.1. Price: 7/6, post free 8/-.

***BRITISH STANDARD INSTITUTION**

(No. 1501-1506 : 1950). Steels for use in the chemical, petroleum and allied industries. Publishers: British Standards Institution, 28, Victoria Street, London, S.W.1. Price: 12/6.

DIRECTORY OF DIRECTORS, 1950

Publishers: Thomas Skinner & Co. (Publishers) Ltd., 330, Gresham House, Old Broad Street, London, E.C.2. Price: £2.

GREAT BRITAIN—MINISTRY OF LABOUR—FACTORY DEPARTMENT

Memorandum on explosion and gassing risks in the cleaning, examination and repair of stills, tanks, etc. 1948. Publishers: H.M.S.O., York House, Kingsway, London, W.C.2. Price: 4d.

KERSTEN, C.

Der Stahlhochbau: ein Leitfaden für Studium und Praxis. Vol. I, 5th edition, 1949. Publishers: Wilhelm Ernst & Sohn, Berlin. Price: DM 16.60.

***LAWTON, V. H.**

Examples of structural steel design (Part 2) to conform with the requirements of British Standard 449, 1948. (*British Constructional Steelwork Association, Publication 2-1950.*) (In this publication the author deals with the design of the valley beams and stanchions in the two examples illustrated in Part 1). Publishers: British Constructional Steelwork Association, Artillery House, Westminster, London, S.W.1.

***MICHAELS, J.**

Contemporary structure in architecture. Illus. 1950. (The author has succeeded in bridging the gap between the way of thinking of architect and engineer. Every major structural system has been analysed and compared with other systems. In the first section the skeleton frame is studied with reference to methods of joining members, and in the second, structure in architectural design is discussed. The book contains 259 photographs of great interest and beauty and 75 drawings.) Publishers: Reinhold Publishing Corporation, 330, West 42nd Street, New York 18. Price: 8 dollars 50 cents.

***MOND NICKEL CO. LTD.**

The magnetic properties of the nickel-iron alloys. Illus. 1950. Publishers: Mond Nickel Co. Ltd., Sunderland House, Curzon Street, London, W.1.

***NATIONAL CENTRAL LIBRARY**

34th Annual report of the Executive Committee for the year ending 28 February, 1950. 1950. Publishers: National Central Library, Malet Place, London, W.C.1.

***VAZQUEZ, F. B.**

Tensiones residuales. Illus. (*Reprinted from "Tecnica Metalurgica, 1950, Aug.*)

***WHITE, W. F.**

Vrynwy Aqueduct: fourth instalment pipeline. Illus. (*Reprinted from "Journal of Institute Water Engineers, 1950, Feb.*) (This paper contains data on welded aqueduct pipelines.)

WILSON, W. M., MUNSE, W. H., and SNYDER, I.S.

Fatigue strength of various types of butt welds connecting steel plates. Illus. 1950. (*University of Illinois. Engineering Experiment Station. Bulletin Series No. 384.*) Publishers: University of Illinois, 358, Administration Building, Urbana, Illinois, U.S.A. Price: 50 cents.

TRADE CATALOGUES

SAMUEL FOX & CO. LTD.

Some notes on alloy steels containing lead. Illus. 1950. Address: Stockbridge Works, nr. Sheffield.

JOHNSON, MATTHEY & CO. LTD.

(a) Sil-Fos silver brazing alloy. 1946. **(b) Silver brazing alloys.** 1949. **(c) Easy-Flo brazing alloy.** Sept. 1949. Address: 73/83, Hatton Garden, London, E.C.1.

HENRY WIGGIN & CO. LTD.

(a) The Nimonic series. (b) Nimonic 90. (c) Notes on methods of joining Nimonic alloys. (d) The engineering properties of Monel, nickel, Inconel. 1950. Address: Wiggin Street, Birmingham, 16.

A. S. YOUNG & CO. LTD.

Colmonoy diamond setting powder for setting diamond tools for dressing and truing operations, diamond dies, etc. Address: Tower House, Woodside Lane, London, N.12.

NOTES FROM THE BRANCHES

Birmingham.—The first meeting of the session took place on 13 October, with an address by the Chairman, Mr. R. E. G. Weddell, this being his second year of office.

The paper, illustrated by lantern slides, dealt with Machine Fabrication Shop Practice, in its widest sense. Some of the suggestions were purposely provocative to promote a discussion. Many members voiced their views, and a number of interesting and controversial matters were ventilated. At the conclusion of the meeting the Chairman referred to the work of the Institute in furthering the interests of welding, and made special reference to the American Welding Society, who are working on similar lines to our Institute, particularly in their plans regarding the regulations governing membership.

East Midlands.—The summer programme included visits to two works. The first was that of Messrs. Robert Jenkins & Co. Ltd., of Rotherham, and took place on 14 June. This Company produces a large variety of goods and employs numerous methods of welding. The visitors showed particular interest in the pressure vessel and tank departments, the latter being to some extent mechanised, both from the welding (automatic) and handling points of view.

The second visit was to the Stanton Ironworks Co. Ltd., near Nottingham, on 20 September. The party was again led by the Branch Chairman, Mr. G. Drysdale. Mr. W. S. Mathews (Training Officer) of the Stanton Company, in welcoming the members, gave a brief outline of the apprentice training scheme operated by the company. A tour of the very well-equipped Training Centre was followed by a visit to the blast furnaces, and later to the "Spun Plant," where cast-iron pipes were being mass produced in centrifugal casting machines, and the excellent organisation of the works was very apparent.

East of Scotland.—The first meeting of the session was a visit to the North of Scotland Hydro Electric Scheme at Clunie and Pitlochry on 31 October. Under the guidance of a representative of the Hydro Board, the party of twenty-five members inspected the "Scheme," the magnitude of which can be well imagined in view of the fact that it has taken some five years to build.

At the second meeting of the season, two most interesting sound films in technicolor were shown, entitled "The Manipulation of Corrosion and Heat-Resisting Steels" and "Some Applications of Firth-Vickers Special Steels."

Mr. J. A. McWilliam, T.D., M.A., of Firth-Vickers Ltd., gave a short introductory talk on each film and then dealt with the numerous questions raised by members of the audience.

Liverpool.—A large party visited the Vulcan Foundry, Newton-le-Willows, Lancs, on 9 September. The tour included the laboratories, well equipped for routine testing of materials, and shops where the visitors saw many examples of modern streamlined locomotives in various stages of construction. Electric, diesel and steam locomotion were all to be seen.

Ship Repairs.—The Branch held its first lecture meeting of the session on 10 October, when their President, Mr. George Davenport, read a paper entitled "The Welder's Angle on Ship Repairs." He dealt mainly with contraction and the uses to which its effects can be put. A few typical repairs were described in detail, including (1) Boiler combustion-chamber plate cracked; (2) Welding in of circular plates in rigid sides; (3) Double-bottom shell plates for renewal; (4) Building up worn cast-iron gypsy wheel.

Mr. Davenport laid great stress on thorough preparation of a combustion-chamber plate, including the building up of the edge with new metal (buttering) before commencing the weld proper, and cutting the edges on the "J" principle to obtain complete penetration with a sealing bead from one side only. The ends of the earlier runs should be left visible to ensure perfect joining up. He advised reinforcing to compensate for the weld area being less than 100 per cent.

Experience with circular patches indicated that dishing the patch about 3/16 in. was necessary, the contraction straightening the plate on cooling. The procedure recommended was to weld upwards from the centre at the bottom in one pass.

The same principle was applied in cutting a 15 ft. shell plate ¼ in. too long, and jacking up during the welding of the second end. The sides are welded last. The result leaves the weld in compression instead of tension.

Cast-iron gypsy wheels could be welded in the shop by oxy-acetylene (using ferro-silicon rods) when pre-heating would be necessary, but more conveniently on site by studding and using nickel rods for the first runs round the studs, to get a better bond on to the cast iron. Mild steel could be used for subsequent filling. The lecturer had found peening to be an advantage. Finally, Mr. Davenport stressed the need for the highest quality of workmanship, and knowing and certifying the best welders.

During the discussion, which was very lively, Mr. Pridgeon wanted to know if the thickness of circular patches made any difference, and whether the plates were tacked in. He said he thought the lecturer had a lot more up his sleeve than he was telling the audience.

Mr. Jefferson emphatically maintained that the welds should be 100 per cent., and that there should be no need to allow for poor quality work.

Mr. Bryce, surveyor, in moving the vote of thanks, said they were allowed a margin of safety on welds because they knew there were other than good welders. Some insurance companies allowed only 45 per cent.

Mr. Tregaskis seconded, and the President, in replying, said he would feel his talk had been worth while if it had made his audience want to do better welding rather than thinking of what they were going to make out of it.

Work of B.W.R.A.—In accordance with the policy of holding combined meetings with local technical bodies, the Branch, on 2 November, joined with the lately-formed Liverpool Metallurgical Society. Mr. C. S. Milne, the President of the Institute, attended. A talk on the recent work of the B.W.R.A. was to have been given by the Director of Research, Dr. Taylor, but, owing to his absence at the head of the Productivity team in America, it was ably presented by Mr. W. K. B. Marshall, until recently Assistant Director of Research.

Opening the proceedings, the Chairman, Mr. Edwards (President of the Liverpool Metallurgical Society), said it was appropriate that the joint meeting should be devoted to this subject, which included so much common ground.

Mr. Marshall, in his address, gave an interesting account of the growth and work of the B.W.R.A. He emphasised that though the chief problem investigated by the Association had been the weldability of steel, research had also been undertaken on many other problems, good results having recently been obtained in the argon-arc welding of aluminium alloy plates, the spot welding of light alloys and various structural problems.

In proposing the vote of thanks to the lecturer, Mr. Milne said that the Institute was proud of having started the B.W.R.A. and of its remarkable growth in recent years. Mr. Griffin, seconding, referred to the fact that Mr. Marshall is an old student of Liverpool University and a pupil of Dr. Kennett, a past Chairman of the Branch.

Sheffield.—On 26 September upwards of thirty Branch members paid an interesting visit to the Broad Oak Works of Messrs. Markham & Co. Ltd., at Chesterfield. The Company are manufacturing very large water turbines for various hydro-electric

schemes all over the world, and these are the largest fabrication of the type ever attempted in this country. Full use is being made of welding in conjunction with castings and wrought plate and sections, and the Company is justly proud of its effort. The hearty thanks of the Branch are due to Messrs. Markham & Co. Ltd. for their kindness and hospitality.

On 17 October the first lecture meeting of the new session was held. Mr. A. McConnell gave a most interesting exposition of the Thermit Welding Process. After an introductory talk describing the fundamentals of the Thermit reaction and the history of the process, a practical demonstration was held in the open air. A crucible containing 16 lbs. of Thermit mixture was ignited and reacted and some fifteen seconds later 10 lbs. of white hot steel was tapped into the waiting mould.

After this display of pyrotechnics a technicolor sound film was exhibited. This showed the fabrication of stern frames for Liberty Ships and a number of other interesting American applications. The evening was then wound up by a long and interesting discussion and question time, in which many of the practical details regarding the usefulness and method of application of the Thermit Process were described and commented upon.

South London.—The opening meeting of the session was held on 12 October. Mr. E. Seymour-Semper, President of the Branch, opened the meeting.

Two films were shown, "Welded Structures by Dorman, Long & Co. Ltd," a record of some of the welding carried out on the site at Abbey Works, and the Firth Vickers film, "The Manipulation of Corrosion and Heat Resisting Steels."

South Western.—The opening meeting was held at Bristol on 13 October. A very excellent lecture entitled "Some Considerations in the Design and Detailing of Welded Structural Steelwork," illustrated with lantern slides, was given by Mr. H. Roscoe.

Many illustrations were given of riveted work and its counterpart n welded design, much to the advantage of the latter in its clean lines and lightness for the same strength, and because a designer can make up his requirements using standard flats, angles, etc.

A most interesting feature of the lecture was that, after showing the theory by drawings and graphs, the lecturer could show what had already been done along these lines by some of the more progressive firms, both in this country and abroad.

At the close of the lecture Mr. Roscoe answered questions put by members.

Tees-Side.—Sixty-four members of the Branch visited the I.C.I. Wilton Works, near Middlesbrough, on 7 September. After inspecting the new tunnel which connects Teesport with the I.C.I. Billingham Works on the North Bank of the river Tees, the party were taken to the main site where a new road, to replace the existing road connecting Middlesbrough with Redcar, is nearing completion. Here the structure containing the necessary equipment for manufacturing petroleum dominates the rest of the works. The numerous all-welded pressure vessels with the inevitable accompaniment of a maze of pipes and valves presented a fine spectacle of British engineering enterprise.

The Perspex and Bakelite plants were the last sections to be visited, and were extremely interesting in the scope and intricacies of the methods of manufacture of these products.

Steelwork for Margam.—There was an attendance of 120 at the opening lecture of the 1950-51 session, when a film lecture entitled "The Margam Project" was given by Mr. E. Ibbotson, M.I.Struct.E., of Messrs. Dorman, Long & Co. Ltd. The meeting was honoured by the presence of the President of the Institute, Mr. C. S. Milne.

Mr. E. Clark, the Branch Chairman, expressed apologies for the absence of the Branch President, Mr. Chetwynd Talbot, and thanked the retiring Chairman, Mr. J. Jackson, for his work whilst in office.

Mr. Ibbotson showed a series of slide pictures giving details of the manipulation and welding of the crane girders designed to carry two loaded cranes of 300-ton capacity at the Steel Co. of Wales, Abbey Works, Margam. These girders are 110 ft. long by 12 ft. 5 ins. deep, over 3 ft. wide flanges, and have a moment of inertia of 1,500,000 in.^{4} The weight is 90 tons each and there are 22 in number.

Details of the weld preparations were shown by slide film, the speaker pointing out the advantages of welding over rivets on a job of such a colossal size. Many enlightening factors on the economy of using the welding technique were brought out.

The sound film which followed dealt in detail with the operation, describing the various progressive movements of the steelwork. The form of the girder and the position of the various joints were determined by the largest size of material which could be obtained from the mills and by the capacity of the flattening and planing machines in the fabricating shop.

Before any welding was done, full-size specimens of butt joints were prepared and welded under normal conditions. When inspected it was found that no modification in design was necessary. The welding of the 2¼ in. think flange plates and the flitch plates was carried out as vertical welding, by 8-gauge electrodes for the first run followed by 6-gauge electrodes. For the butts in the web plates ¼ in. diameter deep penetrating electrodes were used in the first run followed by normal 4-gauge electrodes. The stiffeners were welded to the web with continuous fillet welds, carried out in the horizontal-vertical position.

The importance of the weld procedure was emphasised and was strictly adhered to as follows:

1. Butts in the flange plates welded.
2. Butts in the web plates welded.
3. Butts in the flitch plates welded.
4. Stiffeners welded to the webs.
5. Web welded to the flitch plates.
6. Flitch plates welded to the flanges.
7. Feet of the stiffeners welded to the flanges and flitch plates.

The operations Nos. 1, 2 and 3 allow material to shrink freely in its length before being restrained by any longitudinal welding. The welding of the stiffeners causes further shrinkage in the longitudinal direction. After this shrinkage has taken place, longitudinal welds 5 and 6 can be carried out. By using this procedure no cracking was experienced, and the complete girder was free from distortion.

All welds were tested by the supersonic process.

The transfer of these girders to the site, the new Melting Shop, was shown in detail and the erection of a girder by a huge jib crane was of great interest to the audience.

West of Scotland.—The opening meeting of the Branch was held on 18 October, when a paper entitled "Welding and Erection of Plate Girder Bridges" was read by Mr. William Girvan. The bridges referred to in this paper were those designed to replace the seven bridges which spanned the river Eye at different crossings of the main rail line from Edinburgh to Berwick, the original bridges having been destroyed in the August floodings of 1948. Many lantern illustrations used in the presentation of this paper showed the extent of the damage caused to the bridges and surrounding embankments, the work of reclamation of the embankment, the preparation for temporary bridge supports, supports for the new bridges, detail drawings for the bridge girders, welding sequences, and final erection of the new bridges on site.

An interesting feature about this paper was the combined efforts of the four engineering trades, namely, the Civil in the work of reclaiming the land and preparing the bridge supports, the Structural in constructing and erecting the temporary and new bridges, the Welder in supplying the completely welded bridge, free from distortion and of sound construction, and the "designer," the Railway Engineer responsible for detail and design. In the course of his address, the speaker commented on the efficient manner in which the railway engineers worked and their co-operation with the contractors throughout every phase of the work, which assisted so much in the success and speed with which the job was carried out. Two illustrations showed clearly the foresight of the Railway Executive in their selection of the

temporary bridge structures, which were arranged to make a simple dismantling job for the erector when he came to erect the permanent bridges.

An interesting discussion followed the lecture.

Wolverhampton.—The official investiture of the new chairman, Mr. Colin Spencer, took place at the opening meeting of the session on 20 September. The subject of Mr. Spencer's address was "Architectural Metalwork, Agricultural Implement and Production Welding." Many slides were shown illustrating ornamental gates and railings, firescreens and baskets, electric light standards, lamp-shades and weather-vanes; heavier and simpler items were also shown, including fire-escapes, balconies, cattle-pens and the like.

The production of the many beautiful, intricate and often unique examples of architectural metalwork, such as those illustrated, is the work of highly skilled craftsmen. The use of welding, both oxy-acetylene and electric arc, developed for such articles when, around 1912, steel began to replace wrought iron. This made the craftsman's task in many ways easier, while the articles themselves became stronger, with the disappearance of riveted joints and their proneness to corrosion. A further advance has been the use of certain light alloys of aluminium which are now weldable.

It is possible where quantities are involved to jig-weld railings, gates and similar items of fairly simple design, and thus to reduce the cost appreciably by comparison with riveted types.

Mr. Spencer paid tribute to the work of the Rural Industries Bureau, which had enabled several thousands of men in the rural areas to receive instruction and become proficient in the art of welding. These men were the successors of the village blacksmiths, and their work, often similar to that shown in the slides, illustrates the continuity of skilled craftsmanship.

Turning to the use of welding in the manufacture of agricultural implements, Mr. Spencer showed a very fine selection of slides illustrating various implements and tractor attachments, among them being ploughs, cultivators, root harvesters, potato planters and lifters, ridgers, ditchers, beet toppers, hayrakes and the like.

Resistance Welding.—At a meeting held on 18 October, a paper was given by Mr. C. A. Burton, entitled "Recent Developments in Resistance Welding Technique."

As an introduction to the paper, a new American film, entitled "This is Resistance Welding," and lent by Messrs. Johnson, Matthey & Co., was shown. This covered the general technique of resistance welding and its uses, and proved a useful background to Mr. Burton's later remarks.

Mr. Burton, after describing the single-phase resistance welder and showing slides of various types, including several special purpose machines of great interest, dealt with the general characteristics of these machines. The chief disadvantage of the single-phase machine was the very high current demand made on the power supply system; this was accentuated in the case of the portable machine with its long cables to the actual welding head. As an example, Mr. Burton compared the welds made on 16-gauge material with a single-phase machine. The power absorbed by the pedestal type of machine with, say, a 12-in. throat would be of the order of 27 KVa (9,000 amperes × 3 volts). The portable machine with 7-ft. cables would take 108 KVa (9,000 amperes × 12 volts). Thus the current demand on the mains would be four times as great with the portable machine.

It is possible with certain articles, where their shape lends itself to the technique, to employ what is known as "Series Welding." In this development the welding current flows downwards from electrode to article through one spot weld to a copper contact block below, and returns upwards through a second spot weld on another part of the article back to the machine. The effect is that of reducing the machine throat and accordingly the losses, thus the current demand on the mains is much reduced.

Among the special machines described and illustrated was one for the manufacture of ferro-concrete reinforcement; this machine has 32 heads, fed from 16 transformers with 32 secondary windings; 32 welds in one row can be made simultaneously, and it is possible to make 14 rows of welds per minute.

Another machine, designed specially for tubular chair manufacture, welds tubes down to 18-gauge thick, the thinnest tube that will withstand the closing pressure.

A big factor in resistance welding is surface condition of sheet, especially aluminium. This "picks up" readily on the electrodes, and since it is possible to reach welding heat at high spots in 1/200 of a second, this can give a great deal of trouble.

The three-phase machine is the answer to many of the objections raised against the single-phase machine. Its first development was in the form of the stored energy capacity type, but more recently the reactance type has been developed. The former stores energy in a condenser charged from all three phases, and this is discharged by a contactor when the weld is required. In the latter machine the energy is stored by means of a welding transformer with a variable core gap, and is released when required by a contactor.

With the 3-phase machine the line current may be reduced by as much as 75 per cent. with consequent big reduction in power demand; there is uniform heating on all three lines, and the power factor exceeds 85 per cent.; the secondary current remains the same whether dealing with thick or thin sections, and insulation costs are reduced. Heating up takes place over a longer period, and on aluminium sheet there is much less "pick-up" than with the single-phase machine.

Mr. Burton later described hot riveting, a process allied to resistance welding. It was superior to cold riveting by reason of the complete filling that takes place, and because there is also some adhesion. The electrodes used should be flat where they contact the plain end of the rivet, and not curved, since with this latter shape the contact is only on the circumference of the end instead of over the whole circular area; thus there is a heavy load on the contact circle with consequent damage to electrodes. In the course of discussion after the paper, Mr. Burton defended British methods of clamping electrodes, and stated that many of the troubles users encountered could be avoided by proper maintenance.

Asked what was the maximum thickness of mild steel that can be resistance-welded, Mr. Burton gave two ¼-inch plates as a general figure for this country, though in America this had been exceeded.

Asked at what point resistance welding became uneconomical compared with arc-welding, Mr. Burton answered that for sub-assemblies and light work generally, especially where the work can be adapted for resistance-welding, that process is usually cheaper.

Answering other points, the lecturer said that steel having up to 0·35 per cent. carbon content can be satisfactorily welded without post-heating, and up to 0·6 per cent. with post-heating. Projection welding of studs has the advantage that no ceramics need be used, and there is negligible flash; the usual maximum diameter of studs is 3/8 in. for this process. Hot riveting is mostly used for rivets between 1/8 in. and 3/8 in. diameter, and equipment costs might be prohibitive for larger sizes.

Indian Branch.—The Branch is now holding meetings in alternate months. Its Annual General Meeting took place at Calcutta on 14 July last, when the following officers and Committee were elected: *President*, Sir L. F. Misra, Kt.; *Chairman*, Mr. N. W. T. Hain; *Vice-Chairman*, Mr. F. K. Tubby; *Secretary*, Sri N. G. Chatterjee; *Treasurer and Assistant Secretary*, Sri B. N. Majumdar; *Members of the Executive Committee*, Dr. A. H. Pandyn, Messrs. A. M. Kapadin, D. S. Desai, W. J. Gameson, T. R. Shields, M. N. Mohindra.

A paper on "Practical Application of Welding to Steel Structures" by Mr. F. J. Coleman was then read, and the film "Oxygen in Industry" was shown by courtesy of the Indian Oxygen and Acetylene Co. Ltd. The paper is to be published in the journal of the (Indian) Association of Engineers.

On 28 September last a paper entitled "Summary of Welding and its Progress," by K. Kunjithapatham, was read, and the films "Middlesbrough Bridge Construction" and "Fabrication of Steel Parts" were shown.

THE WELDING OF ALUMINIUM ALLOYS, PARTICULARLY FOR STRUCTURAL APPLICATIONS

By W. K. B. MARSHALL, B.Eng., A.I.M.

This paper, read to the Institute on 25 January last, surveys the present state of knowledge regarding the welding of aluminium alloys, with special reference to structural applications. Dealing first with the properties of the alloys and with the basic metallurgy of the welded joints produced in them, the author considers the advantages and disadvantages of the various welding processes applicable and ends with some comments on the influence of welding on the design of structures in aluminium alloys, pointing out the need for service data.

IN the last few years aluminium alloys have become well established in the structural field. Previously one was accustomed to thinking of aluminium in terms of domestic utensils, of special equipment for the chemical and food industries, and of high performance alloys for use in the construction of aircraft. For these applications the alloys have been divided fairly rigidly into the low strength ones which are weldable, and the high strength ones which are not weldable.

With the application of the metal to a wide variety of structural uses, including building, ship-building, transport and general engineering, this division into weldable and non-weldable alloys is no longer acceptable. Structural engineers are not seriously interested in the low strength alloys, but require to weld the higher strength ones, particularly those in which the strength is achieved as a result of heat treatment. Moreover, industry demands that the welding of aluminium should no longer be regarded as a job for the specialist and that a method should be developed which would enable the general run of constructional shops to fabricate the alloys with as little fuss as they fabricate mild steel structures. It is also necessary that fillet welding, previously considered undesirable, should become an accepted method of construction; it would be inconceivable in structural applications to limit the designers to butt welds, as is the practice in the traditional field of aluminium welding. Further, since many structural applications involve bigger components than is normally the case with aluminium, site welding and positional welding become of greater importance.

Again, distortion, an accepted feature of aluminium welding, requires to be brought more under control, since the usual practice of shaping up the job by subsequent hammering or rolling of the welds is not normally acceptable.

Against all these demands it is comforting to note that in many ways the quality of welding required for structures is not normally expected to reach the standard demanded of welds in, say, aluminium pressure vessels. This applies particularly to the corrosion resistance of the joint and the general finish, and in certain cases to the strength of the joint.

It is clear that there has been a change in emphasis regarding the sort of aluminium alloy which is required to be welded, the type of joints required and the quality demanded in the finished joint. Although the problems raised by this change are still far from solved, something is known about the behaviour in welding of many of the difficult alloys and there are sufficient data available to permit general principles to be set down. It is the object of this paper to discuss these general principles and examine how they can be of assistance in choosing the welding process for the job and in assessing the probable performance of the structure when welded. The approach is mainly metallurgical, since at the present stage the problems involved are in most cases metallurgical. The engineering aspects are left to those more competent to discuss them than the present author.

The paper will deal first with the properties of the materials which are to be welded, then with the basic metallurgy of welded joints produced in these materials, and thirdly with available processes. The final section will attempt to show how metallurgical factors and practical considerations introduced by the welding process affect design and the performance of the finished structure.

Materials

Details of the principal types of aluminium alloys are given in Table on page 183. The traditional welding-quality aluminium alloys are pure aluminium, in various grades from 99.0 per cent. to 99.99 per cent. aluminium, 1¼ per cent. manganese alloy, 10-13 per cent. silicon alloy, and 2-3 per cent. magnesium alloy.

Pure aluminium is used mostly as the commercially pure metal containing 99.0 to 99.4 per cent. aluminium, with iron and silicon as the main impurities. The 1¼ per cent. manganese alloy has slightly higher strength than pure aluminium and almost identical corrosion resistance for many applications. The magnesium-containing alloys are appreciably stronger and with 3 per cent. magnesium give a tensile strength of about 14 tons/sq. in. in the soft condition. Although all the above are readily welded by the oxy-acetylene process, considerably greater difficulty is met with the magnesium-containing alloys than the others.

Metal arc welding is occasionally employed when conditions permit or justify it, and more recently argon arc welding is finding considerable application.

As noted earlier, with the possible exception of those containing magnesium, these alloys are not attractive for structural work where strength is the prior consideration. At the same time they may be used for lightly stressed parts such as panels, ducting, etc., where easy formability is an advantage.

Alloys with magnesium content in the range 5 to 7 per cent. are normally considered border-line as far as welding is concerned. In the past they have occasionally been welded in an effort to reduce section and save weight, but generally speaking the tendency has been to avoid their use, because of the uncertain strength of the welded joint and general difficulties in fabrication. Now, however, the extension of aluminium alloys to shipbuilding and similar applications demands the use of alloys of this type. The expedient of thickening the section and using the more tractable pure aluminium is no longer permissible, because of the increase in weight involved.

The heat-treatable alloys have up to the present been considered unsuitable for welding. This is mainly because of the uncertain loss of mechanical properties caused by welding and the cracking which occurs in the welding operation. Nevertheless, heat-treated alloys of the AW10 type (1 per cent. silicon and 1 per cent. magnesium) have been welded to some extent and the loss in properties accepted. The welding of alloys of the duralumin type has seldom been attempted seriously, since, in addition to its uncertain strength, the welded joint has been brittle and of relatively poor corrosion resistance.

The foregoing summarises the position as it appeared until quite recently. In the last few years, however, there have been developments both in the metallurgy of the alloys to be welded, and in the welding processes themselves which suggest ways in which some of the previous difficulties may be overcome. These developments have already had some practical repercussions,

but generally speaking we are at the stage of investigating all the ways in which our newly found knowledge can be applied, and of accumulating data which will enable the welding of the difficult alloys to be carried out with more confidence. It is the intention to discuss in the following section recent metallurgical developments in aluminium welding against a background of what was already known about the metallurgy of aluminium welds.

Basic Metallurgy of Aluminium Alloy Welds

The metallurgical problems associated with the welding of aluminium alloys can be conveniently sub-divided into three groups, viz. (1) those concerned with the properties of the weld deposit; (2) those arising from the effect of the welding heat on the parent metal; and (3) those concerned with the tendency to crack during welding. There are other aspects, but the above are probably the most important and have certainly received most attention in recent years.

Considering first the weld deposit, it is axiomatic that the object of any fusion welding process is to lay down a deposit with a strength at least equal to that of the parent metal. It is also

Fig. 1. Fracture through an argon arc weld in ½" thick aluminium — 7% magnesium alloy, showing massive oxide inclusions resulting from faulty welding technique.

usually necessary that the deposit should have reasonable ductility. This ideal can readily be achieved in the case of pure aluminium, the 1¼ per cent. manganese alloy and the low magnesium alloys. There are, however, certain difficulties in the case of the higher magnesium alloys and the heat-treated alloys.

In the case of the high magnesium alloys there are a number of factors which tend to reduce the strength of the deposited weld metal below that of the parent plate. The most important of these are the intrinsically lower strength of the cast weld metal compared with wrought metal of the same composition, porosity, loss in magnesium content and other defects such as lack of fusion, oxide inclusions, etc. The relative importance of these factors varies with the welding process employed. For instance, with gas-welding the slow solidification of the deposited metal means that the low intrinsic strength of the cast deposit is the factor which determines the strength of welds in thick plate. In this process there is little loss in magnesium and only slight porosity in the deposit. In the case of metal arc welds, however, whilst the rate of solidification should be fast enough to give a strong cast structure, the weld deposit is in fact considerably weaker than in gas welding, due amongst other things to the heavy loss in magnesium which occurs during the transfer of the metal across the arc and to bad porosity, arising from moisture in the electrode coating[1].

Argon arc welding appears to combine the best of both worlds in this respect, in that there is little loss in magnesium, negligible porosity and the solidification rate is fast enough to ensure good intrinsic strength. With this method of welding the strength of the deposit may be increased further, and in fact may be made to exceed that of the parent metal by the use of a filler rod somewhat higher in magnesium content. Moreover, the ductility of the deposit made under these conditions is very satisfactory, being of the order of 20 per cent. on all-weld metal samples. On the other hand, since flux is not used in argon arc welding there is a danger of retaining in the deposit massive oxide films which may seriously interfere with its strength (Fig. 1). The presence of these films, however, appears to be associated with welding technique and can be avoided by skilled operators.

Some of the above-mentioned factors apply equally in the case of heat-treated alloys. There is also with these alloys another difficulty arising from the fact that the properties of the parent plate have been achieved only by heavy mechanical working followed by heat treatment. Since in structural work it is seldom possible to apply full heat treatment subsequent to welding, it is obviously impossible in such applications to attain anything like full parent metal strength in a deposit made using parent metal as a filler rod. Even when heat treatment is feasible, parent metal strength is seldom achieved and with many alloys the ductility of the deposit is alarmingly low.

Gas-welding of heat-treated alloys gives a coarse-grained deposit of low strength. Metal arc welding gives porosity, although this can be more easily reduced than in the case of the aluminium-magnesium alloys, by thorough drying of the electrodes. The deposit is still of low ductility, however, and there is inevitably some loss of magnesium when this element is present.

As with the aluminium-magnesium alloys the trouble appears to be minimised by the use of argon arc welding, since this at least reduces the porosity and ensures that there is little change in the composition of the metal during deposition. There is, in fact, evidence that in the case of AW10 alloy virtually full parent strength can be obtained with argon arc welds heat treated after welding.

A further possibility where heat treatment subsequent to welding is not feasible is to deposit a filler metal which has a high intrinsic cast strength. This may be done by gas, metal arc or argon arc welding, depending on other requirements. Voldrich, in America, has used alloys containing 5 to 10 per cent. silicon with small amounts of copper, which as deposited by the argon arc process have strengths approaching 20 tons/sq.in.[2] The 7 per cent. magnesium alloy with a strength of 18 to 19 tons/sq. in. when deposited by the argon arc is also promising in this respect.

It will be seen from the above, therefore, that on the basis of existing knowledge it is possible with the high magnesium alloys to obtain deposits of a strength about equal to that of the annealed parent metal. With the heat-treated alloys deposits of a strength approaching 20 tons/sq. in.[2] are possible without heat treatment. Argon arc welding offers the best chance of achieving these results. At the same time the low ductility of all these deposits does not permit of any working of the joint subsequent to welding as is practised in the case of pure aluminium welds.

Effects of Welding Heat

Whether or not the strengths quoted above for the deposit are achieved on the complete welded joint depends on the extent to which the properties of the adjacent parent metal are affected by the welding heat.

The welding heat may affect the parent metal in a number of ways. First, in the case of an alloy with a long freezing range,

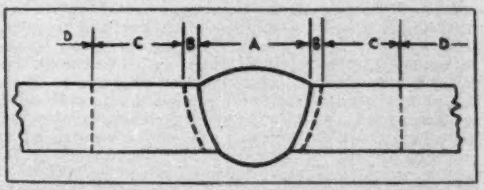

Fig. 2. Simple diagrammatic section through a weld in aluminium alloy showing:—

(a) the weld deposit
(b) the partially melted parent metal, and
(c) the heat affected but unmelted area of the parent metal.

partial melting of the parent metal may take place immediately adjacent to the deposit. Secondly, with work-hardened alloys, such as cold-rolled sheet, annealing of the metal in the neighbourhood of the weld will occur. Thirdly, in a heat-treated alloy there will be a softened zone adjacent to the weld. The occurrence of these effects is illustrated diagrammatically in Fig. 2.

Partial melting does not take place to any appreciable extent in the case of pure aluminium and the aluminium-manganese alloy. In the case of the magnesium-containing alloys, however, and the heat-treatable alloys with their long freezing range, partial melting inevitably occurs. The extent of the partially melted zone for a given alloy is clearly dependent on the temperature gradient adjacent to the weld during welding. Thus it is wider in gas welds than in arc welds and, generally speaking, in welds in thick sections than in those in thin sections.

One effect of the partial melting is to reduce the mechanical properties of the material immediately adjacent to the deposit to a level only slightly higher than that of the deposit itself. This

Fig. 3a

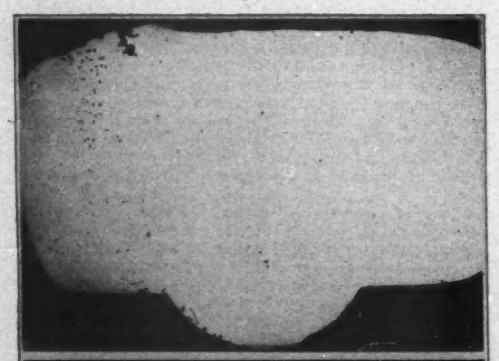

Fig. 3b

fact presents a very serious problem in the welding of the high strength alloys. Although at the moment it is often masked by a more serious reduction in properties in other parts of the welded joint, it may eventually emerge as the principal factor limiting the strength which may be achieved in welds on these alloys. For instance, it has already been shown that the properties of the deposit itself can be improved by using special filler-rods. Again, as discussed later, the reduction in properties in the unmelted, heat-affected zone of the parent metal can be counteracted by producing an alloy which shows a more sluggish response to heating. But the semi-cast structure adjacent to the weld is not likely to be affected by either of these two expedients. It raises the fundamental problem of producing a high strength wrought alloy which is also strong and ductile in the as-cast state, and for that reason sets a limit to the effectiveness of the expedients suggested above.

Another effect of the partial melting in the case of magnesium-containing alloys is to allow pockets of gas to form in the molten phase and give porosity when this phase solidifies. In bad cases the presence of the porosity can have a serious effect on the strength of the welded joint. The British Non-Ferrous Metals Research Association traced the trouble back to the casting stage of the parent metal and showed that it could be reduced to negligible proportions by special foundry technique, including effective degassing and the avoidance of melting fluxes containing sodium and some alkaline earth metals (Fig. 3, 4). As a result of this work, material is now available commercially which is virtually immune from trouble in this respect, although fabricators are sometimes called upon to weld non-welding quality material produced by the old method. In these cases it is important to remember that since the amount of porosity is a function of time and temperature, the effect is more marked with slow welding and thick plate. Compared with gas welding, argon arc welding reduces it very considerably, but even with this process it is necessary to use properly de-gassed material if porosity is to be avoided altogether. The phenomenon and its effects in the case of 5 per cent. magnesium alloy argon arc welded are illustrated in Figs. 3 and 4. Fig. 3a shows a section of an argon arc weld in gassy plate, and 3b a section through a similar weld in de-gassed plate. Fig. 4 indicates how the tensile fracture occurs through the porous zone in the gassy plate at an ultimate tensile strength of 13 tons/sq. in., compared with 16 tons/sq. in. for a sound weld.

In the case of cold-rolled or drawn material the welding operation usually causes complete annealing of the adjacent parent metal. This annealed zone extends for a distance on each side of the weld depending on the welding conditions. Its extent is greatest with slow welding and thick plate, whilst metal arc and argon arc welding give a narrower zone than gas welding. Curve B in Fig. 5 shows a typical hardness plot across a weld in such material. Proof stress and tensile strength values follow the same pattern as this curve, whilst ductility values follow an inverse pattern. The general effect of the annealing on an average welded joint is to reduce the tensile strength to that of the annealed metal, and no amount of subsequent working of the weld deposit can restore the properties of the joint.

The case of heat-treated alloys is very similar to the above. Since in any but the smallest structures it is quite impossible to heat-treat after welding, it is usually necessary to weld the material in the solution treated and aged condition. Welds made in the alloy in this condition have a zone of softened material near the weld, although the hardness distribution as shown in curve C (Fig. 5) is not quite identical with that given by cold worked alloys. It will be noted that immediately adjoining the welds there is a slight peak where the metal has been raised above the solution temperature and cooled fairly rapidly. Outside this there is a valley where the metal during welding has reached a maximum temperature somewhere between ageing temperature and solution temperature and a reduction in hardness, tensile strength, and proof stress values has occurred. Some alloys, notably those containing copper, often show a second valley due to complicated over-ageing and reversion phenomena.

The degree of softening occurring on welding varies with different alloys. AW10, which is the most popular structural alloy at the moment, is very readily softened, whilst an alloy containing

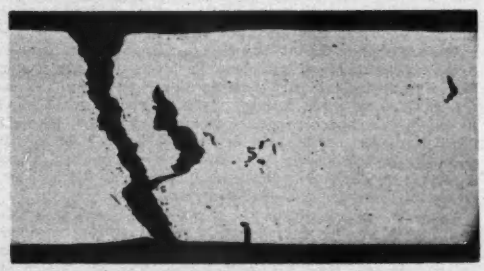

Fig. 4. Section through a fractured tensile specimen from an argon arc weld in ½" thick undegassed aluminium — 7% magnesium alloy showing break through the porous area at the side of the weld.

for instance 5 per cent. silicon and 2½ per cent. copper is affected only slightly when welded under average conditions.[5] The effect is associated with the rate of response of the alloy to heat treatment, and it is clear therefore that its elimination will be achieved only in alloys with an extremely sluggish response. It is true that arc welding and high welding rates will reduce the effect, but all the existing commercial heat-treatable alloys display the phenomenon to an undesirable degree.

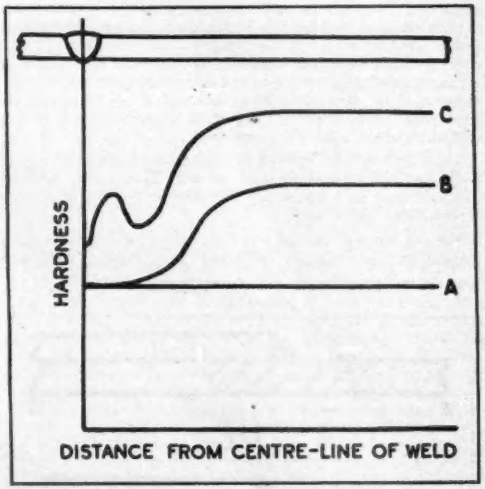

Fig. 5. Hardness distribution in the neighbourhood of welds in various types of aluminium alloys.

(a) Annealed pure aluminium or non-heat-treatable alloy.
(b) Cold-worked pure aluminium or non-heat-treatable alloy.
(c) Heat treated alloy.

Cracking and its Prevention

The remaining metallurgical effect with which we are concerned is that of cracking during welding. Cracks in any weld are undesirable, but in the case of the relatively brittle deposits characteristic of the high strength aluminium alloys they are especially dangerous.

The tendency of an alloy to crack when welded has always been associated in a vague sort of way with the freezing range of the alloy, but it was not until the British Non-Ferrous Metals Research Association carried out their investigations into the associated phenomenon of hot-tearing in castings that a quantitative assessment of the phenomenon was possible.[6] More recent work at Birmingham University has taken matters further, and for simple alloys at least it is now possible to say with some certainty to what extent an alloy is likely to crack, from a knowledge of the equilibrium diagram concerned,[7, 8].

The cracking referred to here is that which occurs during the actual welding operation either along the centre of the weld or in the partially melted zone immediately adjacent to the weld. The position of the crack is usually determined by the amount of reinforcement on the weld, a heavily reinforced weld tending to crack at the boundary and a light one at the centre. The underlying reason is the same in each case.

Without going into a detailed explanation of why one alloy cracks and another does not, it can be said that the investigations referred to above show that the tendency to crack is associated with the temperature interval between the point at which the alloy first becomes coherent (and thus has some strength) and the point at which solidification is just complete. This temperature interval is found to be related to the freezing range of the alloy so that in the case of a simple alloy system comprising partial solid solubility and an eutectic, it is zero with the pure aluminium, rising to a maximum with progressive additions of the alloying element and falling to zero again at the eutectic composition. The tendency to crack follows a similar pattern. The effect when additional elements are present, although similar in principle, can only be explained by reference to the particular alloy system.

This knowledge is important to welders, because it indicates alloys to be avoided when the welding is to be carried out under severe restraint and suggests ways of overcoming cracking troubles with the difficult alloys. In this latter connection an expedient which immediately suggests itself and and one which has proved itself in practice is the use of a filler-rod which has a lower melting point than the alloy being welded and which is itself more resistant to cracking. In this way the difficult alloy at the weld boundary is allowed to become completely solid (and thus out of danger of cracking) whilst the weld metal is still liquid. When the weld metal itself solidifies it does not crack because of its intrinsic resistance. Thus, for example, when welding the magnesium-containing alloys, cracking can be minimised by using a filler-wire somewhat higher in magnesium content than the parent metal. Again, for the same reason, the aluminium-5 per cent. silicon rod with its low melting point and high intrinsic resistance to cracking is a useful general purpose filler rod for many alloys which might otherwise crack in welding. It is necessary, however, to ensure, in these and similar cases, that the alloying elements in the rod do not form with the parent metal some low melting point phase of poor cracking resistance.

The foregoing has been concerned with the intrinsic tendency of an alloy to crack. There is also the other aspect of cracking which is associated with bad design and bad technique. This is not peculiar to aluminium alloys and the factors involved have been fully discussed elsewhere. It is interesting to note, however, that the use of either argon or metal arc welding can often overcome cracking in an alloy which cracks in gas welding. This is a further argument in favour of this method of welding for the alloys under consideration.

Welding Processes

It is now intended to discuss the more common welding processes in some detail. The most important of these are gas welding, metal

Fig. 6. Jig welding of ¼" thick aluminium — 7% magnesium alloy plates by the argon arc process.

arc welding and argon arc welding. Other processes such as atomic hydrogen welding and carbon arc welding are used on aluminium but to a very limited extent.

Considering first gas welding, although aluminium may be welded by any of the oxy-fuel gas processes, of these oxy-acetylene is the one best suited to the welding of structures. As noted earlier, however, gas welding must be of limited use for structures for a number of reasons. First, there is considerably more distortion in gas welding than in arc welding. Secondly, there is always the difficulty of removing flux residues with consequent uncertainty about the possibility of corrosion at the joint; and thirdly, with some alloys the strength of the completed weld is lower than can be achieved with, say, argon arc welding. There is also the point, mentioned earlier, that cracking is more likely to occur with

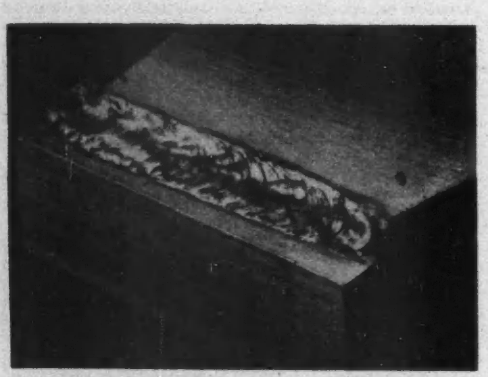

Fig. 7. Fillet weld in ¼" thick aluminium — 1% magnesium — 1% silicon section made by the argon arc process.

gas welding than with arc welding. On heavier structures there is in addition the slowness of the welding to contend with. At the same time, gas welding is so versatile a process that it will almost certainly continue to find use in the welding of light gauge panels, ducting, etc., particularly where there is difficulty in achieving an accurate set-up.

The metal arc welding of aluminium alloys has been practised with indifferent success for many years now. Where there is a special problem to be overcome, such as distortion, cracking, or the repair of castings, the process has found limited application, but the difficulties in manipulation and the relatively poor quality of the welds have prevented extension to a wider field. Electrodes have been produced for most of the common alloys, but in practice those which are used are limited to pure aluminium, 5 or 7 per cent. magnesium alloy and 5 per cent. silicon. The pure aluminium

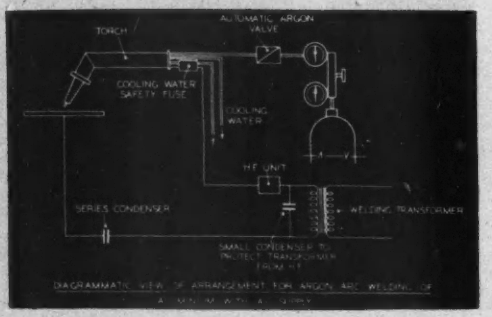

Fig. 8. Circuit diagram of the equipment used in the argon arc welding of aluminium.

electrode has been used in welding vessels for the chemical industry, where the corrosion resistance required demands the use of pure metal, whilst the 5 per cent. silicon electrode is a general purpose electrode for metal arc welding in all other applications and for all alloys except the aluminium magnesium ones.

Metal arc welding of aluminium requires considerably more skill than that of mild steel. Butt welds normally require backing plates and pre-heating is usually necessary if consistent penetration is to be obtained. Welding can be carried out without pre-heating, but penetration then becomes irregular, the weld is beady and porosity in the deposit is increased. This porosity is a feature of all aluminium metal arc welds and appears to arise mainly from moisture in the electrode coating. Although it can be reduced by pre-heating of the plate and drying of the electrodes, it is very difficult to avoid under shop conditions.

The available electrodes for aluminium alloys normally require the use of a D.C. welding generator with the electrode positive, although reasonable results can be achieved by using A.C. with superimposed high frequency.

The slag residues left after metal arc welding, although corrosive towards the aluminium, do not appear to be quite so dangerous

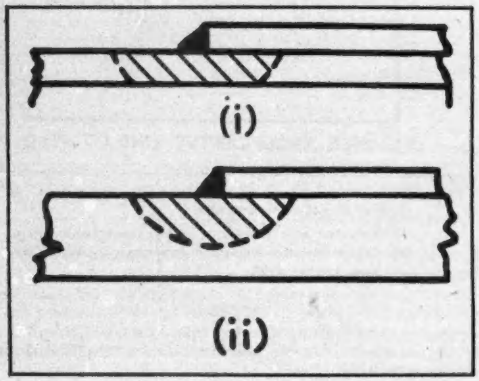

Fig. 9

as those left by gas welding. Thus, if complete immunity from flux corrosion is desired, it is necessary to avoid fillet welds, but there appears to be evidence that the risk is not serious in some applications, notably where the structure is in a dry atmosphere or alternatively where it is regularly washed by rain.

The strengths achieved in metal arc welds vary from that of the fully annealed parent metal with pure aluminium and aluminium 1¼ per cent. manganese alloy to some low erratic value with the high magnesium alloys and the heat-treated alloys. With the higher magnesium alloys the loss in magnesium during welding and the weld porosity reduce the strength to little more than 50 to 60 per cent. of that of the annealed parent metal. With the heat-treated alloys the strength of butt welds made with 5 per cent. silicon alloy is normally about 50 per cent. of that of the fully heat-treated alloys, but on occasions can drop to as low as 30 per cent. The exception appears to be the AW10 alloy, where the deposit is normally stronger than the annealed parent metal and fracture in butt welds therefore occurs in the annealed zone at the side of the weld at a consistent strength of 50 to 60 per cent. of that of the fully heat-treated metal.

The use of electrodes similar in composition to the metal being welded gives very little improvement on the above, unless the joint is subsequently heat-treated.

The above account of the position with regard to metal arc welding may appear to suggest that for the high strength alloys this process has very little future. This, however, may not be the case. In certain structures it is possible to design so that the weld takes very little load or is of such dimensions that the load per

inch is comparatively low. Under these conditions (and possibly with the development of electrodes which will deposit intrinsically high strength material) the convenience of the metal arc process ensures that it will continue to find some application.

Argon Arc Welding

More recently the welding of the difficult aluminium alloys has been given a considerable fillip by the development of the argon arc welding process. It has been shown that this process can deposit high quality weld metal in a wide range of alloys without the use of flux. Thus any doubts about the possible effects of flux residues are completely removed and fillet welding becomes as safe as butt welding.

The process is being used widely in the United States and is rapidly gaining ground in this country.[9] A wide range of thicknesses can be welded with relative ease, provided equipment of the necessary capacity is available. Moreover, the preparation required for welding is considerably simpler than for arc and gas welding, in so much as quite heavy plate can be butt welded without vee-ing (see Fig. 6). To accomplish this, at present, a backing plate is required for thicknesses greater than $\frac{1}{16}$ in., but no doubt techniques such as vertical welding will be developed, which will enable support for the inside of the weld to be dispensed with in many cases. Fillet welds offer no difficulties in material thicker than $\frac{1}{4}$ in. (see Fig. 7). An important advantage of the process is that, providing sufficient current is available, no pre-heat of the work is necessary to give a well-formed fillet or butt weld. Positional welding, however, is a little difficult, although both vertical and horizontal-vertical welding are possible.

More recent developments in the process have been mainly concerned with the electrical characteristics of the welding circuit. It is found that for best welding, A.C. current is required with a minimum open circuit voltage of 100. Superimposed high frequency current correctly phased with the welding current is found desirable in many cases, although equipment is now available which appears to dispense with this. The main difficulty has been due to the rectification of the A.C. welding current in the cycle in which the aluminium is negative. This is overcome by the use of the open high circuit voltage and superimposed high frequency current. Another difficulty has been the heavy D.C. component which develops in the arc even when rectification is avoided. The effect of this is minimised in practice by inserting a large condenser in series with the arc circuit. The electrical circuit normally used for argon arc welding is illustrated diagrammatically in Fig. 8.

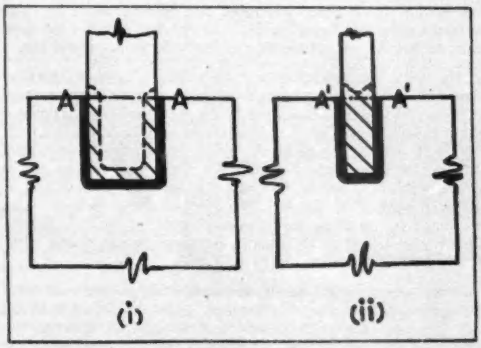

Fig. 10

An advantage of the process from the point of view certainly of the magnesium-containing alloys is that the metal does not pass through the arc during deposition. There is thus very little volatilisation of magnesium and the deposit is normally free from porosity. One possible source of trouble referred to earlier is the formation of oxide skins which may become entrained in the deposited metal and reduce its strength. This, however, may be overcome by correct manipulation.

The process thus solves one of the problems with the difficult alloys, in that it permits the deposition of good quality metal true to composition. It does not, of course, overcome the difficulties with the heat-treated alloys due to the softened zone at the side of the weld.

A disadvantage of the process at the present time is the fact that it is expensive. This is mainly due to the high price of the argon gas and although this will no doubt be reduced in the future, it will always represent a considerable proportion of the welding cost. There is thus an urgent need to investigate the possibility of reducing argon consumption by attention to nozzle design. It is almost certain that considerable improvement can be effected here, since the nozzles at present in use have been designed quite empirically.

It is clear from the nature of the argon arc process that it is best carried out indoors in the absence of draughts. The presence of draughts does not make the process impossible, but it is necessary to increase the argon flow under these conditions.

Another disadvantage which arises when site welding is carried out is the relative clumsiness of the equipment. The need to have argon cylinders in addition to the transformer and other electrical equipment is a nuisance in some instances, but no doubt special equipment will be designed specifically for these conditions.

A more serious disadvantage of the process for structural work is the difficulty of welding in corners and other relatively inaccessible points. Here suitable modification to the design of the structure, possible re-design of the torch, and some ingenuity in manipulation can do much to overcome the handicap.

It appears that the last-mentioned difficulty may also have been overcome by the development in America of the "Aircomatic"

Alloy	Specification for Sheet. B.S. 1470	Typical Mechanical Properties		
		0·1 per cent. Proof Stress. Tons per sq. in.	Ultimate Tensile Stress. Tons per sq. in.	Elongation per cent. on 2 in.
* 99·8 per cent. pure aluminium (annealed) ..	S1A	..	4-5	30
* 99·5 per cent. pure aluminium (annealed) ..	S1B	..	4·5-6	30
* 99·0 per cent. pure aluminium (annealed) ..	S1C	..	5-6	30
* 1½ per cent. manganese alloy (annealed) ..	NS3	3	6-7·5	30
* 2½ per cent. magnesium alloy (annealed) ..	NS4	5-6	11-14	18
* 3½ per cent. magnesium alloy (annealed) ..	NS5	6-7	14-16	18
* 5 per cent. magnesium alloy (annealed) ..	NS6	8-7	17-19	18
* 7 per cent. magnesium alloy annealed) ..	NS7	9-11	20-23	18
1 per cent. silicon, 1 per cent. magnesium alloy (heat treated)	HS10	15-17	19-23	8 min.
Duraluminium (heat treated)	HS15	20 min.	26 min.	8 min.

Table. The Principal Aluminium Alloys showing Typical Mechanical Properties. Alloys marked * are also available with varying amounts of cold rolling to give higher proof stress and ultimate tensile stress and correspondingly lower elongation. Most of the alloys can also be obtained in the form of plate to B.S. 1477, section to B.S. 1476, wire to B.S. 1474 and tube to B.S. 1471.

torch, which enables metal arc welding to be carried out in an argon atmosphere. The electrode in this case is a bare aluminium or aluminium alloy wire which is fed forward continuously at a very rapid rate. Argon gas issues through a nozzle round the wire and surrounds the arc and molten metal. The source of current is a D.C. generator, and it is claimed that once the proper welding conditions are established the intrinsic characteristics of the arc enable the correct arc length to be maintained automatically. The welding gun is so designed as to permit welding in difficult corners and, moreover, it apparently makes overhead welding possible. As far as weld strength is concerned, information is so far available only on the use of pure aluminium and aluminium-silicon type electrodes, and it appears that there is some slight sacrifice in the quality of the welds as compared with tungsten arc welds. It also remains to be seen whether the process is satisfactory with filler wires containing appreciable quantities of magnesium.

The conclusion which arises from the above summary is that some form of argon arc welding is undoubtedly the best all-round possibility for welding the high strength alloys, supplemented perhaps by the use of high strength metal arc electrodes for certain of the heat-treated alloys.

Design

The basic principles of design in pure aluminium in the traditional applications are well known. They comprise the virtually exclusive use of butt welds in an effort to achieve the cleanest possible lines free from crevices, etc., which would result in the lodgment of corrosive liquids. This must still be the basis of design where aluminium alloys are used in the chemical and food industries but with structures quite different considerations arise. These considerations follow from what has been said on the metallurgical aspects and welding processes.

It has already been stated that except for certain special applications such as ducting and shaped panels the use of gas welding is not recommended. Where it is used, it is necessary to anticipate the need for rectifying distortion after welding and thus in the case of thin gauge metal at least, both sides of the weld should be accessible.

In the welding of heavier gauges, metal arc or argon arc are the most likely processes, and here, in the case of butt welds, it is necessary to design so that backing plates can be used, and to allow for their removal after welding. In this connection it is sometimes possible to design the parts so that they are self-backing, but this is usually an expensive procedure. It is also preferable at the present stage to arrange as far as possible that the welding is done in the approximately flat position. As noted earlier, positional welding is possible in many cases, but flat welds, because they give fewer manipulation difficulties, are usually superior in quality.

With regard to the strength of light alloy welds, the best that can be expected is the strength of the annealed parent metal, except possibly in the case of the heat-treated alloys where, with very rapid welding and high heat extraction, complete annealing may not take place. It is clear, therefore, that for the moment structures must be designed on the assumption that the weld is of low strength and relatively brittle. In many cases this involves increasing the length of the welds, although there are certain points to be watched when this is applied to heat-treated alloys. With these alloys the properties of the finished structure depend more than with any other material on details of design and on the way in which the weld is executed. The temperature of welding is so much above that required to impair the properties of the alloy, that irreparable damage can be done by uninformed design methods and bad welding technique.

The first point quite clearly is that, subject to achieving the required strength, the amount of welding should be kept to the absolute minimum. The less heat put into the structure, the less the properties of the material are affected.

The second point is that, in order to reduce the amount of softening of the parent metal, the temperature gradient between the weld and the surrounding metal should be kept as high as possible. From the point of view of the designer this means spacing the welds as far apart as possible and using intermittent welding where this is permissible. From the point of view of the welder it means that where the welds are spaced closely, temperature build-up in the job should be minimised by correct welding sequence and, if necessary, allowing the job to cool down at intervals. Another useful expedient is to clamp massive blocks of metal adjacent to the weld in order to absorb the heat. It also means employing the fastest possible welding speed with the minimum of preheat. The possibility of local over-heating is particularly great in attaching small fittings. Here there is a real danger of completely annealing such fittings, unless care is taken in welding.

The third point concerns the intelligent appreciation of the affect of the annealed zone on the strength of the structure. Two examples of this are illustrated in Figs. 9 and 10. Fig. 9 shows two lap welds, the first being between two thin plates and the second between a thin plate and a thick plate. In the first the softened zone has penetrated completely through the under member, the strength of which has been reduced almost as much as if the weld had actually been in that member. In the second case the heat-affected zone has not penetrated the full thickness of the thick plate and the strength of this plate is correspondingly less affected. Incidentally the heat-affected zone would probably be narrower in this latter case in any event, since the mass of the thick plate would produce a steeper temperature gradient adjacent to the weld.

Fig. 10 shows the effect of the heat-affected zones in a joint between a tension member and plate. Assuming that the weld deposit is adequately strong, the weakest points in the joints are the sections A—A and A′—A′. In the case of the wide member, the section A—A comprises some heat-affected metal but also contains some unaffected metal. It is therefore stronger per inch than section A′—A′, where the two heat-affected zones overlap.

The above examples illustrate the difficulty in giving detailed figures with regard to strengths to be expected in welded assemblies in these alloys. Some *ad hoc* work on the strength of various types of joints in heat-treated alloys has been done, mainly in America,[11, 12] but it is difficult to apply the results generally. Fundamental information is required regarding the thermal conditions in the neighbourhood of welds, when made in different sections and at different welding speeds, etc. The effect of these thermal cycles on the properties of the heat-treated plate in the various alloys is then required, and in this way a complete picture of the effect of the welding operation can be built up.

It has been assumed in this discussion that the softened zone adjacent to a weld is a disadvantage. There can be little doubt that the heat-treatment of welded structures to eliminate the zone does improve the elastic properties, but at the same time it is conceivable that from a practical point of view the soft cushion of metal left by the welding heat could be an advantage in protecting the relatively brittle weld deposit from shock loads or inadvertent overloading. This obviously requires investigation.

Again, nothing has been said about the fatigue strength of welded light alloy structures. In view of the heterogeneous structure of light alloy welds it is not surprising that there is very little reliable data on this subject. It would in any case appear desirable to solve the problem of obtaining uniform static strength before serious work on fatigue properties is attempted, unless this were carried out on actual structures to give much-needed information on the standard of weld strength required.

Conclusions

This paper has given very little numerical data on the properties of welds in the higher strength aluminium alloys, mainly because the whole subject is at present in a state of flux. The subject is a very complicated one and an enormous amount of work is still required to be done. However, it is hoped that the principles involved in making welds in the various alloys have been clarified, sufficiently so for the enterprising designer to consider seriously the application of welding in experimental structures. What

appears to be wanted more than anything at the present time is service data, data of the sort that will tell us whether or not the slag residues left by metal arc welding are serious from the corrosion point of view and just what strength is required in an aluminium alloy weld to make a welded structure acceptable. Information of this kind is difficult to obtain in the laboratory, and if it were available it would be more effective than any amount of laboratory data in stimulating the application of welding to aluminium structures.

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10. SOHN and KUGLER, "The Gas-shielded Metal-Arc Welding Process," *Welding Journal*, 1948, vol. 27 (11), p. 913.
11. HARTMANN, HOLT, MARSHALL and ZAMBOKY, "Static and Fatigue Tests on Arc-welded Aluminium Alloy 61 S-T Plate," *Welding Journal*, 1947, vol. 26 (3), p. 129.
12. MOORE, "Static-Strength Tests on Fillet Welds on Aluminium-Alloy 61 S-T Plate," *Welding Journal*, 1947, vol. 26, pp. 10, 593s.

BOOK REVIEWS

Welding of Steel Structures, pp. 32, illus., Braithwaite & Co., Engineers, Ltd,

The foreword to this book, which is issued by Messrs. Braithwaite & Co., Engineers, Ltd., state that its purpose is to give an outline of the elements of practical welding for the benefit of those engineers, designers and draughtsmen who need an introduction to the subject of the welding of steel structures. It is undoubtedly true that knowledge of the use of welding in structural work is not yet so widespread as one would wish, and any move to improve the position is to be welcomed. Within its limited scope and compass, this book achieves its object admirably and concisely.

The first part deals with practical and design aspects of fillet and butt welds, showing their use in making various types of arc welded joints, the method of calculating their strength, the procedures to be followed in depositing welds in downhand, vertical and overhead positions, and illustrating also some of the more common faults that may occur during welding. It is perhaps advisable to comment on one point of detail in this section. The gap between root faces in a single V butt weld is recommended as from 1/32 to 1/16 inch. It is certainly possible to produce a satisfactory weld under such conditions, but many engineers would prefer a wider gap, particularly where root faces are provided. A new British Standard on the Metal Arc Welding of Mild Steel, which should be published during the next few months, recommends for this type of weld a gap of 1/16 to 3/16 in. for material up to 3/8 in. thickness, and 1/8 to 1/4 in. for thicker material.

The second part of the book covers the application of welding in the construction of plate girders, rigid frame joints, lattice bridge members and fixed and rocker bearings for welded bridges. The information in this section relates primarily to bridge construction, although there is much that would apply with equal value to building structures. Where design rules are quoted these are, of course, based on current specifications and codes of practice. A few pages are devoted to the effects of distortion, and the estimation of electrode quantities involved in making various sizes and types of welds.

The book, which is about 12 in. by 8 in. in size, contains 32 pages, and the text and illustrations are well laid out and very clearly reproduced. It is available free of charge from Messrs. Braithwaites.

Application of Arc Welding (Tillampad Bagsvetsning), pp. xvii-327, illus. with three plans, 4to, Elektriska Svetsningsaktiebolaget, Goteborg, Sweden.

This handsomely produced volume contains the prize winning papers from the Esab's Jubilee prize competition of 1949, which was open for papers describing the re-design for construction by arc welding of a machine or piece of apparatus hitherto made by other methods and papers submitting new designs, that is, of objects not previously made or designed for construction by arc welding.

Besides Sweden, the competition was announced only in Belgium, Denmark, Finland, Norway, Portugal, Switzerland and Spain. The papers are arranged under seven headings and the subjects are as follows:—

1200 ton Hydraulic Press by Per V. Norlin and Carl A. Elieson.
Welding Requires Special Design by T. V. Hemmingsen.
All Welded Marine Diesel Engine by John Olsson.
The Application of Arc Welding to Shipbuilding where the Method of Construction has been Modified to Facilitate its Adaptability by C. Hill-Madsen.
Comparison between a Welded and a Riveted Oil-Tight Bulkhead in a Tanker by Gunnar Laessoe Barfoed.
A Report on the Planning and Execution of Structures of Reinforced Concrete in Conjunction with Arc Welded Steel by Eduardo Torroja Miret.
An Attempt to Make the T-section More Serviceable in Building and Bridge Construction by Means of Systematization by Bertil Hagstrom.
Design and Construction of the Mechanical Parts of the New All-Welded Electric Locomotives, Type Co "Co," litt. M. of the Swedish State Railways Board by Vilhelm Cederberg.
The Application of Electric Arc Welding under Wartime Conditions and the Invaluable Results Obtained from it by Nields Ulrik Juel-Hansen.
Description of Repair and Rebuilding of 28-in. Gantry Mast for Pulpwood Conveyer by Jac. J : son Hjartsater.
Automatic Device for Welding Fins to Sections of Furnaces by Ivar E. Glemhorn.
Construction of a Vertical Boiler by Knut Carlsson.
All-Welded Lattice Girders for Railway Bridges Constructed in Steel "ST N" by M. Ros, F. Buhler and G. Ceradini.
Electric Arc Welding of Thick Sections of High Tensile Structural Steel by M. Ros and R. Montandon.
Static and Fatigue Tests with Different Types of Cover Straps Welded on and Machined from the Solid Steel Material and also with Lap Joints by M. Ros and G. Ceradini.

INSTITUTE OF WELDING MEETINGS

The following is a list of Institute of Welding meetings arranged for the months of January and February, 1951, so far as particulars are available at the time of going to press:—

4 Jan. **Leeds Branch**
"Welding and the Designer," by A. G. Thompson, B.Sc.

4 Jan. **Eastern Counties Branch**
"Welding of High Tensile Steels," by H. F. Tremlett, A.R.S.M.

9 Jan. **Liverpool Branch**
"Research on Welded Pressure Vessels and Pipelines," by N. Gross, B.Eng.

10 Jan. **Manchester Branch**
"Application and Developments with Resistance Welding," by R. Bushell.

11 Jan. **Tyneside Branch**
"New Applications of Welding to Feed Heating Equipment and Piping for Power Stations," by J. E. Smith.

11 Jan. **South London Branch**
A Brains Trust on Practical Welding—Arc, Gas and Resistance, at Guildford.

12 Jan. **Birmingham Branch**
"Electrically Welded Tubing," by W. G. Clewlow, F.I.M.

12 Jan. **South Western Branch**
Lecture by E. J. Mitchell, B.Sc.

12 Jan. **East of Scotland Branch**
Film night, at Dundee.

13 Jan. **Southampton Branch**
"Radiographic Inspection."

16 Jan. **East Midlands Branch**
"Principles, Design and Operation of Arc Welding Plant," by W. A. Wrate, A.M.I.E.E., at Nottingham.

17 Jan. **Wolverhampton Branch**
"Electronic Equipment in Welding Control," by R. J. F. Howard.

17 Jan. **West of Scotland Branch**
Film night.

23 Jan. **Sheffield Branch**
"The Welding of Hardenable Alloy Steels," by Dr. K. Winterton.

25 Jan. **South London Branch—Medway Section**
"Argonarc Welding," by R. R. Sillifant, with lantern slides, at Strood.

25 Jan. **North London Branch**
Question Night, at Regent Street Polytechnic.

26 Jan. **East of Scotland Branch**
"Power Factor Correction by Capacitor," by H. Ferguson. Joint meeting with Edinburgh Electrical Society, at Edinburgh.

31 Jan. INSTITUTE MEETING
"Continuous Welded Structures—Abbey Works, Port Talbot," by W. S. Atkins, B.Sc.

1 Feb. **Portsmouth Branch**
Subject: not yet known.

1 Feb. **Tees-side Branch**
"Welded Fabrications," by E. Blakeborough.

1 Feb. **Eastern Counties Branch**
"Argonarc Welding," by W. A. Woolcott, at Norwich.

2 Feb. **Eastern Counties Branch**
"Argonarc Welding," by W. A. Woolcott, at Colchester.

7 Feb. **Manchester Branch**
"Argonarc Welding," by W. A. Woolcott.

9 Feb. **South Western Branch**
"Hard Facing by Welding," by M. Riddihough.

9 Feb. **Wolverhampton Branch**
Sixth Annual Dinner and Ladies' Night.

9 Feb. **Birmingham Branch**
"Automatic Arc Welding," by J. Latimer.

10 Feb. **Southampton Branch**
"Development of Oxygen Cutting in Industry," by E. Ryalls.

14 Feb. **West of Scotland Branch**
"Welding in Oil Refineries," by K. C. Balmer.

15 Feb. **Tyneside Branch**
"Organisation for Ship Welding," by E. Cuthbert, M.I.Prod.E.

15 Feb. **South London Branch**
"Some Aspects of the Design of Welded Machine Frames," by E. C. Moore.

20 Feb. **South Western Branch**
Subject: not yet known.

20 Feb. **Sheffield Branch**
"Welding Earthmoving Equipment in America," by Mr. Kirk.

21 Feb. **Wolverhampton Branch**
"Welding and the Designer," by A. G. Thompson, B.Sc.

22 Feb. **North London Branch**
Lecture at Waltham Cross.

23 Feb. **East of Scotland Branch**
"Welding Applied to Shipbuilding," by T. McIver, at Kirkcaldy.

26 Feb. **East Midlands Branch**
"Argonarc Welding," by W. A. Woolcott, at Derby.

27 Feb. **Leeds Branch**
"Applications and Developments with Resistance Welding," by R. Bushell.

28 Feb. INSTITUTE MEETING
The Sir William J. Larke Medal Paper.

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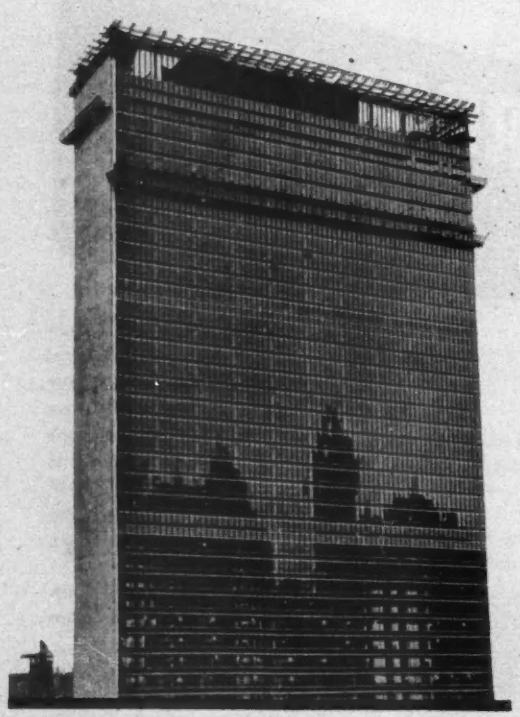

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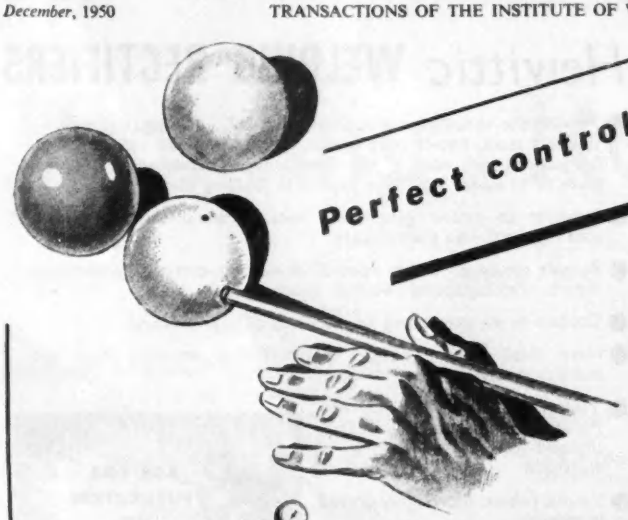

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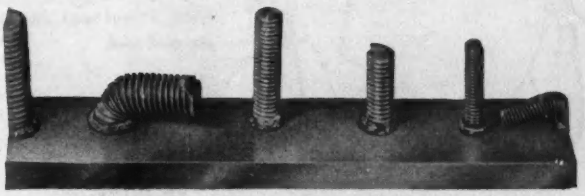

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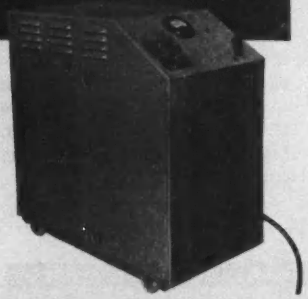

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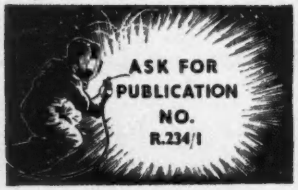

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Welding Research

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Contents

	Page
Association Notes	103r
Tensile Properties of Mild Steel Weld Metal at High Temperatures	104r
Ductility of Mild Steel Welds near the Solidus	125r
Explanation of Hot-Cracking of Mild Steel Welds	129r

Association Notes

Causes of Hot Cracking

In this issue of the journal we are presenting three papers on this important subject:—

1. Tensile properties of mild steel weld metal at high temperatures, by J. G. Ball, B.Sc., A.I.M., and K. Winterton, Ph.D., B.Sc. (see page 104r).
2. Ductility of mild steel welds near the solidus, by E. C. Rollason, Ph.D., M.Sc., F.I.M. (see page 125r).
3. Explanation of hot cracking of mild steel welds, by E. C. Rollason, Ph.D., M.Sc., F.I.M., and D. F. T. Roberts, B.Sc.Tech. (see page 129r).

We are inviting a written discussion on these three papers, and should be glad to get early contributions, as we are hoping to publish the complete discussion in the February issue of the journal.

The first paper, by Ball and Winterton, describes an investigation in which tensile specimens cut from weld metal were heated in a platinum wound furnace, and tested to failure in a tensile testing machine in the range 900 deg. C. to 1100 deg. C. The mild steel weld metal specimens were found to have low ductility compared with the values at higher and lower temperatures. This brittle range should not be correlated with hot cracking, but it appears to be an effect general to cast steel. At higher temperatures (1200 to 1425 deg. C.) the weld metal was found to have very high ductility. The effects of segregation, direction of testing, prior heat treatment, welding current, rate of straining, iron oxide and sulphur content have all been investigated for their effects on the tensile properties.

The second paper, by Rollason, covers the same ground, though a much simpler testing procedure was used. A drop in ductility in the range 1250 to 1350 deg. C. was found in all cases, and this was thought to be connected with hot cracking. The results are correlated with those obtained from the Murex hot cracking machine. The author thinks that the difference in results compared with those obtained by Ball and Winterton is due to the fact that much higher rates of heating were used. Tests are reported for several electrode types and in particular for the effect of manganese additions in the electrode coating.

The paper by Rollason and Roberts gives an up-to-date account of the latest ideas on the causes of hot cracking. Hot cracking is stated to be largely due to the presence of sulphur, with manganese having an ameliorating increase. The silicon and phosphorus affect hot cracking in that they increase the segregation of sulphur. The authors also discuss the effect of pre-heating, welding current, and carbon and nickel content.

R.63

Tensile Properties of Mild Steel Weld Metal at High Temperatures

By J. G. BALL, B.Sc., A.I.M. and K. WINTERTON, Ph.D., B.Sc.

SYNOPSIS

Tensile specimens cut from weld metal were heated in a platinum wound furnace arranged to fit between the jaws of a tensile testing machine. No lagging was used in the furnace, reliance being placed in the vacuum and on reflecting inner surfaces to reduce convection and radiation losses respectively. The tests were made *in vacuo* to prevent oxidation and decarburisation.

In the range 900-1100 deg. C. all the mild steel weld metals tested were found to have low ductility compared with the values at higher and lower temperatures. As the loss of ductility was more pronounced in specimens cut transverse to the welding direction, and also as the ductility could be improved by annealing, it is probable that the effect was due to segregation. On reducing the pick up of impurities from the plate metal by buttering, the effect was diminished. Iron oxide in the deposit does not reduce ductility, and the effect of sulphur is uncertain. The present work has not shown that this region of low ductility is correlated with hot-cracking of weld metal, but it appears that it is an effect general to cast steel. It has been observed in a less marked degree in electrode core wire but not in wrought mild steel plate.

Mild steel weld metal tested at temperatures of 1200-1425 deg. C. has been found to have very high ductility. It has not been found practicable with the present apparatus to test mild steel at temperatures above the solidus, but a few tests on high carbon steel above the solidus showed that the tensile strength and ductility are not reduced to the very low values which might be expected.

Accounts have been appended of two complementary investigations: firstly, on the determination of the percentage and constitution of the oxide inclusions in three of the weld metals; secondly, on the examination of the structures of the same three weld metals under the electron microscope.

1. INTRODUCTION

This work originated as part of an investigation of the problem of hot-cracking in mild steel weld metal. The term hot-cracking refers to cracking occurring in weld metal at elevated temperatures, the surfaces of the crack being characteristically blued by oxidation. The consequences of hot-cracking are obvious but particularly important is its undermining of fatigue and impact strength. In addition it seems difficult to develop electrodes giving high strength deposits without introducing hot-cracking.

It seems likely that hot-cracking is due to some constitutional weakness in the weld metal at elevated temperatures. For instance, most workers have agreed that sulphur has a pernicious influence, and Reeve[1] has shown that hot-cracking can be induced by increasing the sulphur content of the electrode coating, the core wire or the plate metal. He has suggested that for a given set of welding conditions, there is a limiting sulphur content for the weld metal (sulphur limit), which when exceeded leads to hot-cracking. The role that sulphur plays in promoting hot-cracking is not understood, and no one has suggested that sulphur content is the only or even the prime factor involved. There is less agreement as to the influence of other factors—such as carbon, manganese, oxides and other inclusions, gases and state of deoxidation—though Reeve[1] has put forward some valuable evidence and suggestions.

Although welding may be regarded as a special type of casting operation, the unusual conditions make measurements difficult and most of the phenomena involved have not received much attention. For instance, there is little information on the transference of metal across the arc, arc temperatures, or the equilibria between metal slag and arc atmosphere. The rapid cooling of the weld metal (weld quench) prevents equilibrium being established in some of the complicated reactions which are probably similar to those known in steel making. Steep thermal gradients are set up in all directions in the weld, together with a complex system of stresses. The small amount of information does not permit the influence of these factors on hot-cracking to be assessed, particularly as the temperature at which the cracks occur has not been satisfactorily established, except in one special case involving very short runs where Antonioli[2] reported a temperature range of 1350-1000 deg. C. in which the cracks are formed.

It was decided to investigate the relation between mechanical properties and hot-cracking by determining the tensile properties of some mild steel weld metals, by reheating to various temperatures. The tensile specimens were cut from the weld deposits, and particular attention has been given to ductility.

There is not a great deal of published information on the tensile properties of steel at temperatures over 600 deg. C., and where this is available,[3,4,5,6,7] frequently most attention is given to tensile strength.[3,4] However, an exception must be made in the cases of Hall,[5] Dupuy[6] and Piwowarski,[7] who separately investigated the ductility of cast steel at high temperatures. Their results are discussed later.

Mention must be made of the work of Hodge[8] who describes results of tensile tests on weld metal. He is principally concerned with the effects of nitrogen at temperatures in the range of 20-600 deg. C., but he has done some work at higher temperatures.

2. EQUIPMENT

(a) Furnace Construction

The complete furnace unit is illustrated diagrammatically in Fig. 1 and pictorially in Fig. 2. In essentials it consists of Pt./Pt.-10 per cent. Rh winding supported on a mullite refractory tube (A, Fig. 1). The tube is wound for 2½ in. of its 3½ in. total length, and is of small internal diameter

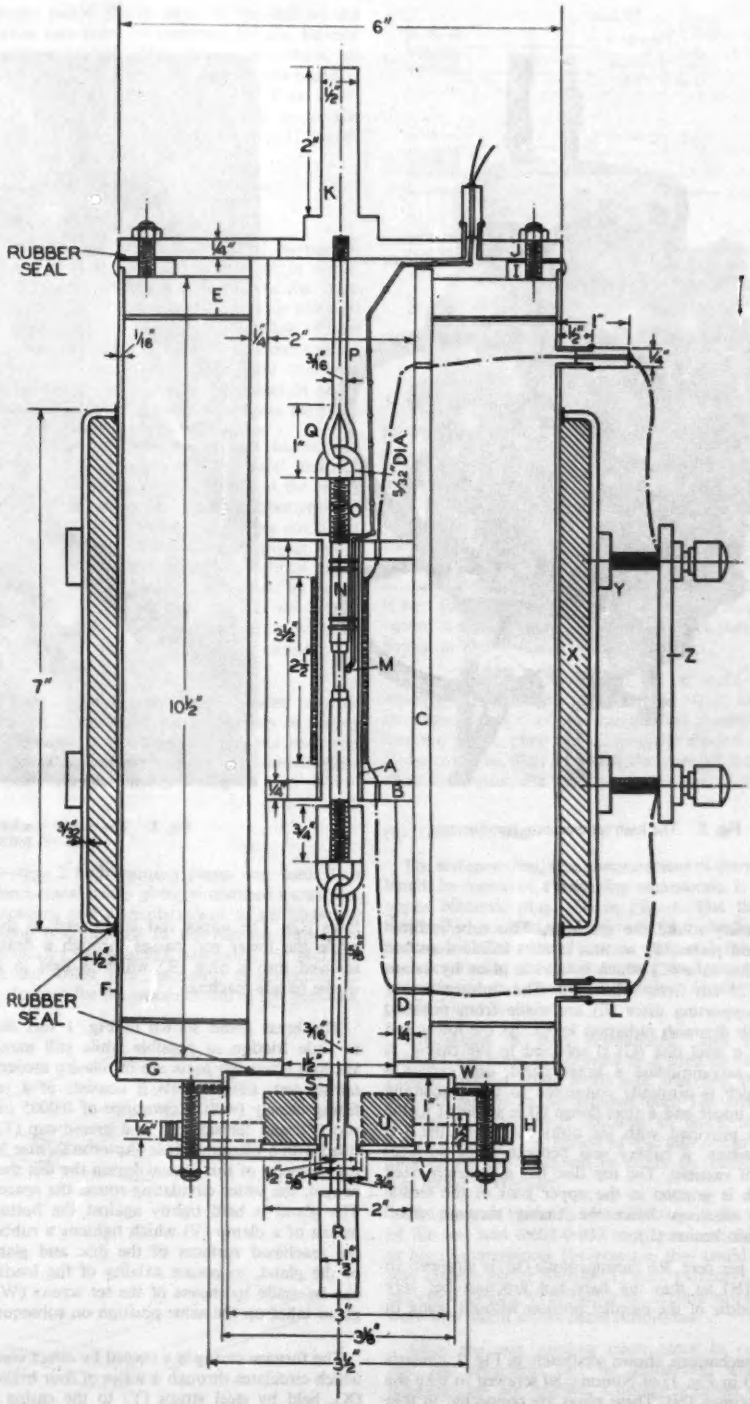

Fig. 1. High temperature furnace (for mechanical tests).

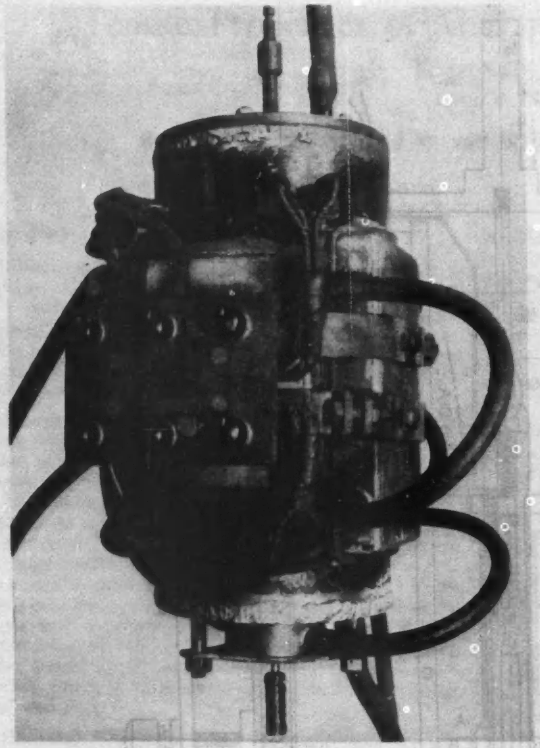

Fig. 2. The high temperature furnace unit.

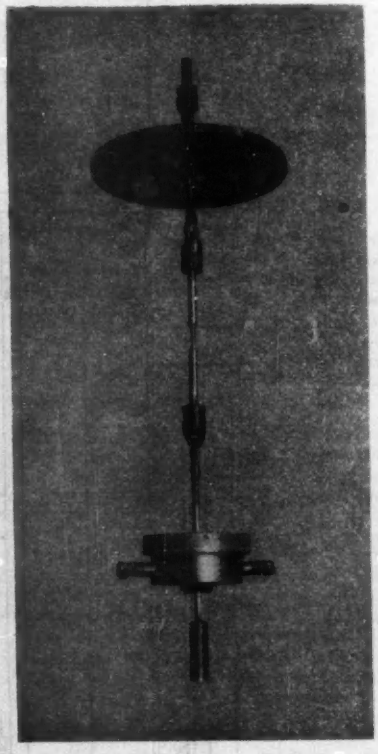

Fig. 3. The tensile mechanism.

to fit fairly closely round the specimen. This tube is fitted with mullite end plates (B) so that it rests inside a second refractory mullite tube (C) which is held in place by means of two discs (E) cut from mild steel. The furnace casing (F) and the supporting discs (E) are made from polished stainless steel to diminish radiation losses. At the lower end of the furnace a steel disc (G) is soldered to the casing. It is recessed to accommodate a brass gland, and carries a nozzle (H) which is normally connected to the evacuating system. At the upper end a steel flange (I) is soldered to the casing, and is provided with six bolts for fixing the top disc (J) in position; a rubber seal between these surfaces prevents loss of vacuum. The top disc has a centrally fixed stud (K) which is gripped in the upper jaws of the tensile machine. The windings leave the casing through small silvered porcelain bushes (L).

A Pt./Pt.-10 per cent. Rh thermocouple (M) is strapped to the specimen (N) so that the bare hot junction lies very close to the middle of the parallel portion without being in contact.

The tensile mechanism, shown separately in Fig. 3, consists of two plugs (O in Fig. 1) of Nimonic 80 screwed to take the ends of the specimen (N). These plugs are connected to thin rods of S.80 stainless steel by means of two stainless steel links (Q). The upper rod is screwed to the top plate (J) while the lower rod passes through a brass gland and is screwed into a plug (R) which is held in the lower grips of the tensile machine.

The brass gland shown in Fig. 1 was designed to have as little friction as possible while still maintaining a high vacuum when the parts are in relative movement during the tensile test. In essentials it consists of a reamed hole (S) fitting closely (with a clearance of 0·0005 in.) to the lower rod (P), and terminating in a grease cup (T) which is kept filled with a vacuum grease (Apiezon Grease M). To maintain the viscosity of this grease during the test the gland is water cooled, the water circulating round the space (U) as shown. The gland is held tightly against the bottom disc (G) by means of a clamp (V) which tightens a rubber seal between the machined surfaces of the disc and gland. Adjustment of the gland, to ensure axiality of the loading mechanism, can be made by means of the set screws (W); once set, the gland takes up the same position on subsequent occasions.

The furnace casing is a cooled by direct contact with water which circulates through a series of four brass compartments (X), held by steel straps (Y) to the casing against rubber seals.

A small terminal board (Z) is fixed to the side of the furnace and carries two pairs of terminals for the furnace windings and the thermocouple. The platinum winding is fed from a 230/80 volt 1·5 K.V.A. fixed ratio transformer supplied by a Variac transformer (continuously variable from 0-230 volts; 9 amp.; 1 K.V.A.). The purpose of this is to provide starting conditions of 37 amp. at 40 volts, falling to 12·5 amp. at 40 volts at 1500 deg. C.

(b) Furnace Design

The unusual procedure has been adopted of having no furnace lagging, since, as the furnace is to work *in vacuo*, convection is at a minimum; radiation losses have also been reduced by introducing reflecting inner surfaces of polished stainless steel as far as possible. The most serious loss of heat envisaged was by conduction away from the specimens along the metallic grips to the tensile machine, and this was minimized by introducing links of austenitic steel in series to give a small area of contact in low conductivity material.

Precautions were taken in the design and during the construction of the furnace to prevent non-axial loading. The outer surfaces of the flange, (I) in Fig. 1, and the recess of the bottom disc (G) which fit against the rubber seals of the top disc and the brass gland respectively, were machined as a single unit after fixing to the furnace casing in order to ensure that these surfaces were parallel. The brass gland was fixed in a central position opposite the top stud by means of the adjusting screws (W); once these are set no further adjustment is required. These precautions, together with the point contact provided by the austenitic links, ensure good alignment.

The brass gland described was designed after a little experimentation, and has been found satisfactory in having low frictional resistance (in practice the frictional load was not measurable on the testing machine) and in maintaining a high vacuum while parts are moving during the test.

(c) The Evacuating System

A Speedivac—type 2 high vacuum pump was used. This is a two-stage mechanical pump giving a nominal vacuum of 0·00001 mm. mercury and a displacement of 48 litres per minute. The pump is connected to the furnace through a drying tube containing phosphorus pentoxide. A McLeod gauge (range 2 mm.-0·001 mm. mercury) is connected in parallel with the furnace for the measurement of low pressure.

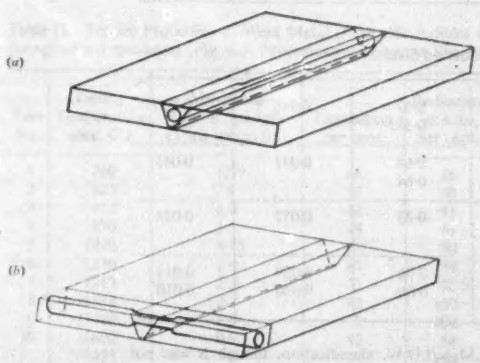

Fig. 4. Position of tensile specimens cut from welded joints.

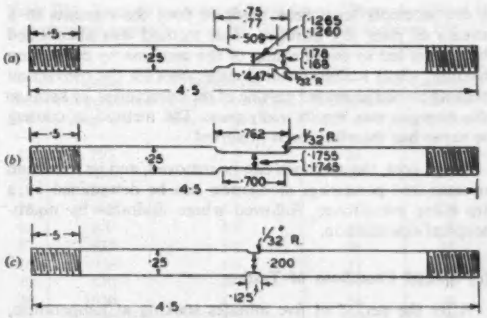

Fig. 5. Dimensions of specimens for tensile tests.

3. GENERAL METHOD

(a) Preparation of the Tensile Specimens

The all-weld metal specimen is cut from a butt-weld made in two mild steel plates as shown in Fig. 4 (a). The 60 deg. "V" is filled with weld metal deposited from the electrode under investigation using two or three runs made under standard conditions. A test specimen is then machined to the dimensions shown in Fig. 5(a) or 5(b). In the early stages of the work the type shown in Fig. 5(a) was used, but when it was found that the screw threads were strong enough to permit a greater diameter in the parallel portion, the shape shown in Fig. 5(b) was preferred.

Some specimens have been cut at right angles to the welding direction as shown in Fig. 4(b), to ascertain the directional nature of the mechanical properties. To avoid fracture in the plate metal, specially shaped specimens had to be cut (Fig. 5(c)) in which the parallel portion was very short and within the weld.

(b) Test Procedure

The test specimen, after measurement of diameter and gauge length by means of a travelling microscope, is screwed to the upper Nimonic plug, (O) in Fig. 1. The thermocouple is strapped in position, and the top end of the furnace is bolted and sealed. The other Nimonic plug and the lower rod are then screwed to the specimen, and the brass gland is slipped over the rod and clamped in position. Finally the lower plug (R) in Fig. 1 is added.

Evacuation is then commenced, and the water-flow through the baths is adjusted to a suitable value. When the vacuum reaches about 0·003 mm. mercury, the temperature is raised rapidly to the required level. The time necessary for heating is about 10-15 minutes to reach temperatures of 1000-1100 deg. C. A period of five minutes at temperature is allowed for the specimen to attain uniformity, after which it is tested to fracture.

The pressure found to be satisfactory at the commencement of the test was 0·003-0·007 mm. mercury; with the furnace at high temperatures the pressure that could be maintained was slightly higher (0·01-0·015 mm. mercury), due mainly to increased gassing of refractories. Scaling and decarburisation were very slight under these conditions.

After the test, cooling takes place in continued *vacuo* and the apparatus can be dismantled when non-scaling temperatures are reached. Cooling is rather slow, owing to the design of the furnace, which tends to conserve heat, so

a few attempts have been made to cool the contents in a stream of pure dry nitrogen. This method was abandoned because it led to over-heating of the contents by convection heating; slight scaling resulted either because the convection heating caused increased gassing of the refractories, or because the nitrogen was insufficiently pure. The method of cooling *in vacuo* has therefore been preferred.

When cool, the specimen can be removed, and its reduction of area and percentage elongation can be determined by a travelling microscope, followed where desirable by microscopical examination.

(c) Special Conditions of Testing

After the period of five minutes soaking at temperature, the temperature is fairly uniform over the gauge length. Measurements showed a variation of temperature between the centre of the gauge length and the shoulder amounting to 2 deg. C. at 800 deg. C. and 5 deg. C. at 1100 deg. C. At higher temperatures the variation may be rather more, and for this reason reduction in area is the more reliable indication of ductility.

At high temperatures, above 1,000 deg. C., a difficulty arose in that welding took place in the screw threads between the specimen and the Nimonic plugs. This was overcome by lightly dusting the screw threads with alumina powder.

The Dennison testing machine used in these tests may be operated at four constant speeds; in practice the highest speed was used corresponding to 0·8 in. per min. The straining rate was therefore approximately constant and equivalent to about 0·025-0·015 per sec., depending on the extension.

4. MATERIALS

Two plate steels have been used (steels 1 and 2), with analyses as shown in Table I, the most important difference between them being in sulphur content.

Tests have been made on a high carbon steel (steel 3), and for convenience its analysis is included in Table I.

The electrodes used are listed with their B.E.A.M.A./I.O.W. classification numbers in Table I, together with the analysis of their weld deposits for the two types of steel plate. The properties of the weld metals from two of these

Table I. Analysis of Steels Used

Mark	Class	C	Si	Mn	S	P
1	—	0·18 0·19	0·038	0·52	0·070 0·073	0·030
2	—	0·13	Trace	0·56	0·041	0·035
3	—	0·85	0·20	0·64	0·028	0·034

Analysis of Weld Deposits on Steel 1

A	E217	0·14 0·14	0·127	0·39	0·060 0·062	0·024
B	E217	0·10 0·10	0·122	0·062	0·044	0·040
C	R416	0·10 0·10	0·041 0·042	0·35	0·062	0·030
D	E537 *	0·07 0·07	0·028	0·09 0·10	0·034	0·024

Analysis of Weld Deposits on Steel 2

A	E217	0·08 0·09	0·085	0·37 0·38	0·045	0·025
B	E217	0·07 0·07	0·16	0·64 0·64	0·031	0·043
C	R416	0·10 0·10	0·062	0·33	0·037	0·028
D	E537 *	0·06 0·06	0·024	0·06 0·06	0·029 0·030	0·011 0·010

* This electrode is of the type E537 of the B.E.A.M.A./I.O.W. classification, though it was not included at the time these experiments were made.

electrodes have been extensively compared, electrode A being chosen as being susceptible to hot-cracking, and electrode B as being relatively free from the defect.

Electrodes C and D having an intermediate and high oxygen content respectively were chosen to investigate the influence of oxygen since electrodes A and B give deposits of low oxygen content.

The remaining electrode (electrode E) is an austenitic steel rod of the 18/8 type.

5. RESULTS

In considering the properties of weld metals at high temperatures in relation to hot-cracking, ductility has been considered of prime importance. Fundamentally the value of ductility decides whether the weld metal can sustain without fracture the self-imposed thermal contractions.

Reduction in area is considered a better index of ductility than percentage elongation, one reason being that it is less liable to error through thermal gradients in the tensile specimen. The view has been justified in practice as reduction in area has given more reliable and consistent results than percentage elongation.

It is not easy to group the investigations which follow into rigid sections, though it may be helpful to attempt this.

(i) Two weld metals were chosen, one free from, and the other prone to hot-cracking, and their ductility was compared over a wide range of temperature. A region of low ductility was found at temperatures of 900-1000 deg. C. being rather more marked for the electrode prone to hot-cracking (section (a)).

(ii) Attempts were made to correlate the region of low ductility with susceptibility to hot-cracking. (Sections (b), (c) and (d).)

(iii) Investigations were made to explain the region of low ductility in metallurgical terms. (Sections (e) to 1 inclusive.)

(iv) The region of low ductility was found to be a general phenomenon of cast steel. Some consideration has been given to the significance of the results at higher temperatures. (Sections (m), (n) and (o.)

(a) Ductility of Two Weld Metals

In the first instance, two electrodes were chosen for examination:—

Electrode A—susceptible to hot-cracking.
Electrode B—relatively free from the defect.

The preliminary results from deposits from these electrodes are given in Tables II and III. Fig. 6 shows the results for reduction in area plotted as a function of temperature. For specimens cut entirely from weld metal (Fig. 4(a)), the curves for weld metal from electrode A and electrode B are shown in thin line and broken line respectively. The two curves show similar features, namely, a minimum in ductility at 900-1000 deg. C., and very high ductility at temperatures above 1200 deg. C.

The minimum in ductility is more marked with the electrode prone to hot-cracking, and appears at a lower temperature. Since the temperature at which hot-cracking occurs was not known, the relevance of these results to hot-cracking was uncertain, and it was decided to make a fuller investigation of the phenomenon.

Table II. Tensile Properties of Weld Metal (Electrode A/Steel 1) (Longitudinal specimens (Fig. 4a); dimensions as shown in Fig. 5a)

Test No.	Testing Temperature (deg. C.)	Maximum Tensile Strength (Tons per sq.in.)	Elongation per cent.	Reduction in Area per cent.
1	710	12·7	46	86
2	825	7·8	58	88
3	915	6·0	44	41
4	970	5·5	48	49
5	1020	4·45	52	60
6	1130	2·9	65	84
7	1223	2·3	73	98·5
8	1318	2·2	81	100
9	1350	1·5	72	100
10	1400	0·9	42	88
11	1425	—	67	100

Table III. Tensile Properties of Weld Metal (Electrode B/Steel 1) (Longitudinal specimens (Fig. 4a); dimensions as shown in Fig. 5a)

Test No.	Testing Temperature (deg. C.)	Maximum Tensile Strength (Tons per sq.in.)	Elongation per cent.	Reduction in Area per cent.
12	705	13·5	36	70
13	756	11·2	43	89
14	825	7·0	68	90
15	915	4·7	31	67
16	920	4·8	52	69
17	935	5·2	46	69
18	958	5·6	39	58
19	970	6·3	—	57
20	1020	4·2	61	68
21	1020	4·2	63	70
22	1100	3·2	49	84
23	1223	2·4	72	96
24	1318	1·6	89	100

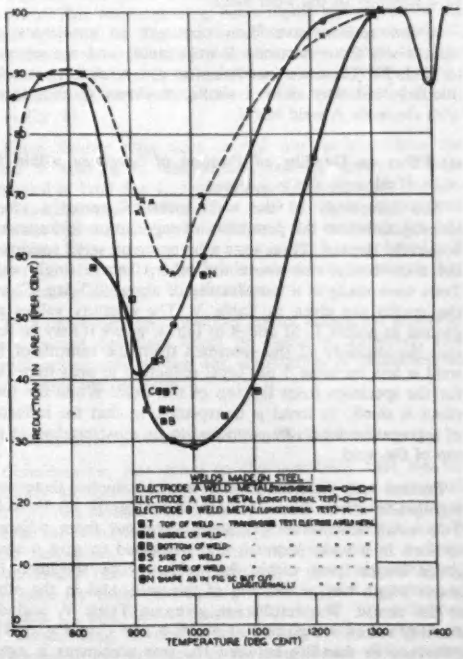
REDUCTION IN AREA (PER CENT)
TEMPERATURE (DEG. CENT)
WELDS MADE ON STEEL 1
ELECTRODE A WELD METAL (TRANSVERSE TEST)
ELECTRODE A WELD METAL (LONGITUDINAL TEST)
ELECTRODE B WELD METAL (LONGITUDINAL TEST)
BT TOP OF WELD - TRANSVERSE TEST ELECTRODE A WELD METAL
BM MIDDLE OF WELD
BB BOTTOM OF WELD
BS SIDE OF WELD
BC CENTRE OF WELD
BN SHAPE AS IN FIG 5C BUT CUT LONGITUDINALLY

Fig. 6. Ductility of two weld metals; effect of direction of testing and position of specimen.

(b) Effect of Direction of Testing on Ductility

It seemed clear that the minimum in ductility referred to above was associated with some constitutional effect in the weld metal. Welds are not symmetrical from the point of view of major segregation; any impurities would tend to be segregated by columnar crystal growth to a central plane parallel with the welding direction.

Consequently it seemed worth while to test the mechanical properties at right angles to the welding direction. This involves the use of a composite weld-plate specimen, and to ensure that fracture occurred in the weld, the shape shown in Fig. 5(c) was found necessary. Here a very short parallel portion is used and the percentage elongation is not measured.

The results for electrode A weld metal are given in Table IV, and the curve for reduction in area is shown in Fig. 6 (thick line). This curve shows similar features to those obtained from all weld metal specimens, but there is a lower value for minimum ductility and this occurs at a higher temperature.

Specimens of this shape might introduce the brittleness associated with notching. A specimen was therefore cut to this shape (Fig. 5(c)) entirely from weld metal, i.e. in the direction of welding. The results are given in Table IV (Test 30), and the reduction in area is plotted as point N in Fig. 6. The joint lies very close to the curve for all weld metal specimens, cut to the shape shown in Fig. 5(a). Similar results were obtained in tests on wrought mild steel (points Y and Z in Fig. 14).

Evidently the changes due to specimen shape are small and may be disregarded. It follows therefore that the different shapes of the two curves for electrode A weld metal are associated with the difference in the direction of testing, i.e. to anisotropy of the weld metal.

A few results have been obtained on specimens cut transversely from electrode B weld metal, and are reported in Table IV. These are insufficient to give a reliable curve for ductility, but they show a similar tendency to that found with electrode A weld metal.

(c) Effect on Ductility of Position of Specimen within the Weld

The anisotropy of the weld metal suggested a closer investigation into the possibility of segregation of impurities within the deposit. Three tests were made on small specimens cut transversely, one above the other, from a single weld. Tests were made at a temperature of about 950 deg. C. and the results are given in Table V. The ductility values are plotted as points T, M and B in Fig. 6, where it may be seen that the ductility of the specimen from the bottom of the weld is less by some 5 per cent. reduction in area than that for the specimen from the top of the weld. While the total effect is small, its trend is unexpected, in that the influence of segregation would be supposed to be most marked at the top of the weld.

Further tests were made to determine whether there were segregation effects from the side to the centre of the weld. Two small transverse specimens were cut from adjacent sections in a wide desposit, and machined to give a short gauge length lying within the weld; in one specimen the gauge length was at the side of the weld, and in the other at the centre. The results are given in Table V, and the ductility values are plotted as points S and C in Fig. 6. The difference in ductility between the two specimens is again small, but it suggests that there is some segregation of impurities towards the centre of the weld.

Table IV. Tensile Properties of Two Weld Metals

(Transverse specimens (Fig. 4b); dimensions as in Fig. 5c)

Weld Metal (Electrode A/Steel 1)

Test No.	Testing Temperature (deg. C.)	Maximum Tensile Strength (Tons per sq.in.)	Reduction in Area per cent.
25	836	9·6	58
26	900	6·0	53
27	923	6·5	35
28	967	5·6	30
29	1000	5·1	29
30*	(1024)	(4·7)	(57)
31	1051	4·6	34
32	1108	3·9	38
33	1205	3·0	76
34	1307	1·8	99·5

Weld Metal (Electrode B/Steel 1)

35	825	6·9	77
36	961	6·7	41
37	993	5·9	48
38	1065	4·4	45
39	1303	1·9	98

* This specimen was shaped as shown in Fig. 5c, but cut longitudinally. It is plotted as point N in Fig. 6.

Table V. Tensile Properties of Weld Metal at Various Points within the Weld (Electrode A/Steel 1)

(Transverse specimens (Fig. 4b); gauge dimensions 0·1 in. dia. ×0·125 in. length)

Test No.	Position*	Testing Temperature (deg. C.)	Maximum Tensile Strength (Tons per sq.in.)	Reduction in Area (per cent.)
40	T (Top)	953	6·0	38
41	M (Middle)	950	6·6	35
42	B (Bottom)	952	7·3	33
43	S (Side)	939	5·6	43
44	C (Centre)	945	5·6	38

* The letters in this column correspond with those shown in Fig. 6.

In these tests (tests 40-44, Table V) it will be noted that none of the ductility values lies on the curve for the normal transverse specimens; this may be due to the fact that smaller specimens were used for these special tests.

(d) Effect of Welding Current on the Tensile Properties of Weld Metal

The weld metal used for mechanical tests was normally deposited at 170 amp. for 8-gauge mild steel electrodes. Since welding current greatly influences the hot-cracking tendency, it was felt that some similar effect might be reflected in the tensile properties.

Tests were therefore made on weld metal from electrode A deposited at 230 amp., and the results are reported in

Table VI. The ductility values are plotted in Fig. 7. The curve is displaced and suggests that the higher welding current has an annealing effect. The higher welding current appears to have less effect on longitudinal specimens, though only a few tests were made (see Table VI).

Table VI. Tensile Properties of Weld Metal (Electrode A/Steel 1) Deposited at a High Welding Current (230 amp.)

(Transverse specimens (Fig. 4b); dimensions as shown in Fig. 5c)

Test No.	Testing Temperature (deg. C.)	Maximum Tensile Strength (Tons per sq.in.)	Elongation per cent.	Reduction in Area per cent.
57	838	6·8	—	68
58	899	6·6	—	39
59	932	6·5	—	34
60	999	5·1	—	49
61	1108	3·3	—	79
62	1215	2·1	—	96

(Longitudinal specimens (Fig. 4a); dimensions as shown in Fig. 5a)

63	851	5·1	60	83
64	897	5·2	36	37
65	960	5·8	34	48

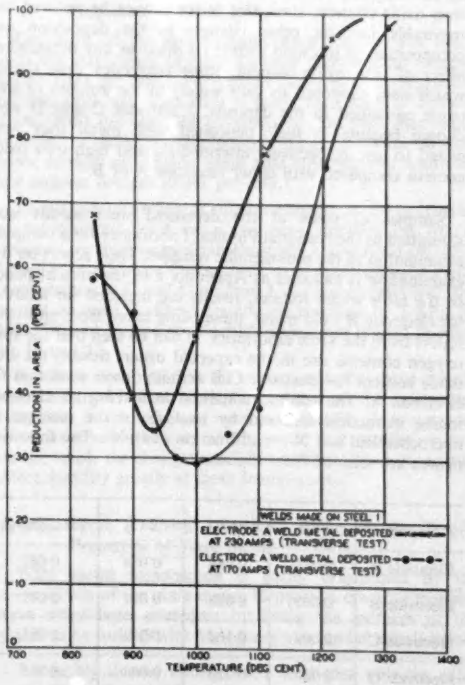
REDUCTION IN AREA (PER CENT)
TEMPERATURE (DEG. CENT)
WELDS MADE ON STEEL 1
ELECTRODE A WELD METAL DEPOSITED AT 230 AMPS (TRANSVERSE TEST)
ELECTRODE A WELD METAL DEPOSITED AT 170 AMPS (TRANSVERSE TEST)

Fig. 7. Effect of welding current on ductility.

(e) Effect on Ductility of Heat-Treatment before Testing

As previously explained, when heating the specimen before testing, a period of five minutes is allowed at the testing temperature to ensure uniformity of temperature over the gauge length. Two tests were made in which this five-minute soaking period was omitted, and the results are reported in Table VII (tests 45 and 50). The ductility values are plotted as points F and L in Fig. 8. Evidently the normal soaking period is desirable, the effect of its omission being as expected.

In explaining the general shape of the curves so far obtained, it was thought possible that:

(i) The minimum in ductility is due to minor segregation of some impurity on the grain boundaries.
(ii) This is accentuated due to major segregation in transverse specimens.
(iii) The effect is increasingly diminished with rising testing temperature by diffusion and homogenisation.

To test the third suggestion, several tests have been made in which various heat treatments were applied before testing. The results are reported in Table VII and the ductility values are plotted in Fig. 8.

Four tests were made in which the normal soaking period of five minutes was extended to twenty minutes. In all cases the ductility was improved, though as might be expected the change was smaller in the heavier section transverse specimens (points M and N in Fig. 8) than in the longitudinal specimens (points G and H).

Next a test was made in which a period of four minutes, soaking at 1200 deg. C. was applied, the temperature then being reduced rapidly to about 925 deg. C., and the test made at the lower temperature in the usual way (point J in Fig. 8). The prior treatment had an adverse effect on ductility. This was surprising, but a repeat test confirmed the result (point K in Fig. 8); the effect remains unexplained. In a similar test in which prior treatment was given for four minutes at 1340 deg. C. before testing at about 1000 deg. C., a considerable improvement in ductility was effected (point R in Fig. 8).

Three further tests were carried out to investigate the effect of soaking at temperature, but the specimens were annealed at 1260 deg. C. for four hours in a separate furnace. The specimens were allowed to cool to room temperature between the annealing treatment and the reheating for test purposes. The ductility values are plotted as points O, P and Q in Fig. 8. Evidently the annealing treatment has considerably improved the ductility.

With one exception, annealing before testing has generally the expected beneficial effect on ductility. However, this would only partly explain the elimination of brittleness at high testing temperatures.

(f) Dilatometric Investigation of Two Weld Metals

Consideration was given to the possibility that loss of ductility at approximately 900-970 deg. C. was connected with the Ac_3 change. For this purpose expansion temperature curves for weld metals deposited from electrodes A and B were determined under heating conditions using a Leitz dilatometer. The critical temperatures were approximately the same for both weld metals, the Ac_3 point occurring at 905 deg. C., and the Ac_2 point at 720 deg. C. The difference in hot-cracking between the two electrodes cannot be attributed to any difference in the temperature of the critical range, and further, this critical range does not coincide with the range of low ductility.

Table VII. Tensile Properties of Weld Metal Heat Treated before Testing (Electrode A/Steel 1)

Test No.*	Prior Heat Treatment	Position of Specimen	Shape of Specimen	Testing Temperature (deg. C.)	Maximum Tensile Strength (Tons per sq.in.)	Elongation (per cent.)	Reduction in Area (per cent.)
45 (F)	Rapid heating, no soaking	As in Fig. 4a	As in Fig. 5a	894	5·3	46	48
46 (G)	20 mins. at 918 deg. C.	,,	,,	918	6·4	41	44
47 (H)	20 mins. at 937 deg. C.	,,	,,	937	6·1	50	58
48 (J)	4 mins. at 1200 deg. C.	,,	,,	923	5·4	27	34
49 (K)	4 mins. at 1200 deg. C.	,,	,,	928	5·4	35	34
50 (L)	Rapid heating, no soaking	As in Fig. 4b	As in Fig. 5c	1183	—	—	60
51 (M)	20 mins. at 923 deg. C.	,,	,,	923	6·7	—	36
52 (N)	20 mins. at 1109 deg. C.	,,	,,	1109	3·8	—	45
53 (O)	3 hrs. at 1260 deg. C.	,,	,,	919	7·3	—	50
54 (P)	3 hrs. at 1260 deg. C.	,,	,,	1011	5·8	—	46
55 (Q)	3 hrs. at 1260 deg. C.	,,	,,	1108	3·8	—	100
56 (R)	4 mins. at 1340 deg. C.	,,	,,	1006	4·7	—	81

* The bracketed letters in this column correspond with those in Fig. 7.

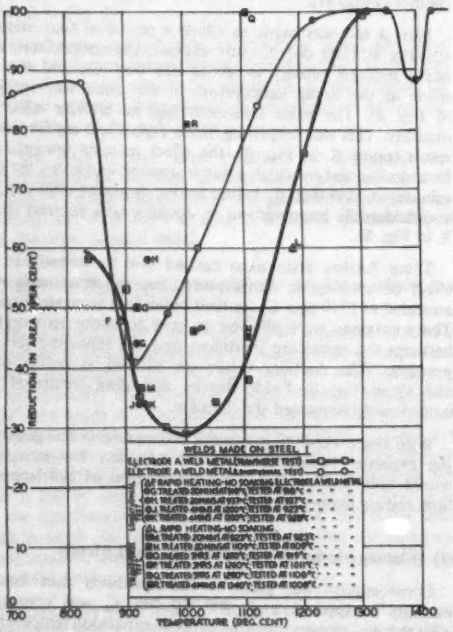

Fig. 8. Effect of prior heat treatment on ductility.

(g) Effect of Iron Oxide Content of the Weld Metal on its Ductility

Dr. L. Reeve drew the authors' attention to some work by A. Niedenthal[9], showing that on some instances, oxygen content has an undesirable influence on the strength and ductility of steel tested at high temperatures in the impact bend test.

Iron oxide content was considered to be a more significant variable than total oxygen content, the latter being merely a summation of the various oxide contents. It is not possible to devise a strictly valid method for investigating the effect of iron oxide content, since this factor cannot be isolated and inevitably involves other changes in the deposition and composition of the weld metal. To discover any outstanding effect of iron oxide content, three electrodes were chosen which were supposed to vary widely in the amount of iron oxide contained in the deposits. Electrodes C and D were chosen because in their deposited weld metal they were stated to give respectively intermediate and high iron oxide content compared with either electrode A or B.

Samples of three of the deposited weld metals were submitted to the National Physical Laboratory for a complete examination of the non-metallic residues. Their report on this examination is included as Appendix 2 of the present paper. In the table which follows, results are included for analyses for electrode B weld metal, these being taken from an earlier report from the same laboratory. It will be seen that the total oxygen contents are in the expected order, though the iron oxide content for electrode C is actually lower than that for electrode A. The method consisted in making an alcoholic iodine extraction followed by analysis of the residues by microchemical and X-ray diffraction methods. The following figures are selected from the results:

Deposit	FeO	MnO	SiO_2	Total Oxygen
Electrode A	0·013	0·084	0·088	0·082
Electrode B	0·0055	0·088	0·081	0·075
Electrode C	0·009	0·164	0·082	0·095
Electrode D	0·700	0·010	0·003	0·163

The chemical compounds present were determined to be as follows:

Electrode A—A high silica content SiO_2, though this was difficult to identify,* together with some manganese sulphide.

Electrode B—Rhodonite (MnFe)O . SiO_2 + manganese sulphide MnS.

Electrode C—A complex silicate 2(Mn . Fe)O . SiO_2. No sulphides were detected.

Electrode D—Iron oxide (FeO) together with some Fe_3O_4. Iron sulphide (FeS) was present.

It should be noted therefore that there can only be traces of free iron oxide present in the deposits from electrodes A, B and C, and that with electrodes B and C the iron oxide is present in combination with silica as complex silicates. It is only with electrode D that substantial amounts of free iron oxide are present in the deposit.

It is now possible to consider the significance of these analyses in relation to the mechanical test results. Mechanical tests were made on all weld metal specimens, cut longitudinally from electrode A, C and D, using steel 2 plate metal. The results are reported in Tables VIII, IX and X, and the ductility values are plotted in Fig. 9.

The value for minimum ductility and its corresponding temperature is different for each type of deposit. The lowest value for minimum ductility is associated with the highest temperature with the lowest iron oxide content. In the case of electrode D, known to contain a large amount of free iron oxide, the minimum in ductility is not quite so pronounced.

It appears that there is little relation between the iron oxide content and the values of ductility in the temperature range 900-1100 deg. C.

(h) Effect of Sulphur Content of the Plate Steel on the Properties of Weld Metal

For most of the investigations plate steel 1 was used, and this was found to have a rather high sulphur content (0·070-0·073 per cent.). As a result the weld metal deposited on this steel will also have a fairly high sulphur content (0·060-0·062 per cent. for electrode A). On the other hand, in order to avoid possible complications, the tests on iron oxide content were made using mild steel plate of relatively low sulphur content (0·041 per cent.).

To examine the effect of sulphur content on the properties of the resultant weld metal, we may compare the results obtained on weld metal from electrode A deposited on steels 1 and 2. In addition, further tests were made on weld metal from electrodes C and D on steel 1, for comparison with the results on steel 2. These results are reported in Tables II, VIII, IX and X, and the ductility values are plotted in Figs. 10, 11 and 12.

It will be observed that the investigation has been mainly restricted to the effect of sulphur content on the mechanical properties in the region of minimum ductility. It is not easy to summarise the results which are in fact conflicting, but on the whole the change in sulphur content does not seem to affect ductility greatly at these temperatures.

(i) The Effect of Using "Padded" Plates on the Tensile Properties of Weld Metal

Weld metal composition is partly determined by the composition of the plate metal. In practice cracking troubles have often been overcome by lining the surfaces of the plates to be welded with high-grade steel (weld metal) before

* Possibly due to combination of titania with the silica in the form of a complex titano-silicate (see Appendix 2).

Table VIII. Tensile Properties of Weld Metal (Electrode A/Steel 2)

(Longitudinal specimens (Fig. 4a); dimensions as shown in Fig. 5b)

Test No.	Testing Temperature (deg. C.)	Maximum Tensile Strength (Tons per sq.in.)	Elongation per cent.	Reduction in Area per cent.
66	814	7·7	52	89
67	921	4·8	63	68
68	1007	5·3	36	41
69	1058	4·3	40	52
70	1106	3·6	49	61
71	1199	2·6	67	98

(Transverse specimens (Fig. 4b); dimensions as shown in Fig. 5c)

72	922	6·7	—	36
73	997	5·6	—	29
74	1003	4·6	—	36
75	1049	4·9	—	45
76	1105	4·2	—	47

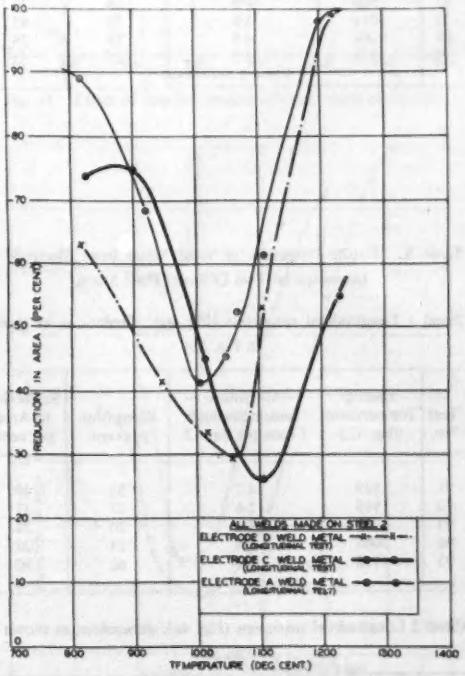
REDUCTION IN AREA (PER CENT)
TEMPERATURE (DEG CENT.)
ALL WELDS MADE ON STEEL 2
ELECTRODE D WELD METAL (LONGITUDINAL TEST)
ELECTRODE C WELD METAL (LONGITUDINAL TEST)
ELECTRODE A WELD METAL (LONGITUDINAL TEST)

Fig. 9. Ductility of three weld metals with various oxygen contents.

Table IX. Tensile Properties of Weld Metal from Electrode C Deposited on Two Different Plate Steels

(Steel 1 Longitudinal Specimens (Fig. 4a); dimensions as in Fig. 5b)

Test No.	Testing Temperature (deg. C.)	Maximum Tensile Strength (Tons per sq.in.)	Elongation per cent.	Reduction in Area per cent.
77	1004	5·9	43	56
78	1051	4·5	32	46
79	1108	4·5	31	39
80	1157	3·5	37	49

(Steel 1 Transverse specimens (Fig. 4b); dimensions as in Fig. 5c)

81	927	7·4	—	50
82	1003	6·3	—	42
83	1045	5·4	—	42
84	1111	3·9	—	40
85	1147	3·8	—	53

(Steel 2 Longitudinal specimens (Fig. 4a); dimensions as in Fig. 5b)

86	824	5·6	56	74
87	900	4·0	54	75
88	1013	5·8	39	45
89	1104	4·5	25	26
90	1228	2·7	45	55

Table X. Tensile Properties of Weld Metal from Electrode D Deposited on Two Different Plate Steels

(Steel 1 Longitudinal specimens (Fig. 4a); dimensions as shown in Fig. 5b)

Test No.	Testing Temperature (deg. C.)	Maximum Tensile Strength (Tons per sq.in.)	Elongation per cent.	Reduction in Area per cent.
91	819	4·7	33	49
92	919	2·6	27	37
93	1000	3·1	20	24
94	1064	3·8	23	28
95	1112	3·3	62	90

(Steel 2 Longitudinal specimens (Fig. 4a); dimensions as shown in Fig. 5b)

96	819	8·5	42	63
97	946	—	30	41
98	1018	4·3	24	33
99	1058	3·9	25	29
100	1106	3·4	32	53
101	1219	2·1	70	99

the final joint is made. By this means plate dilution is reduced from about 30 per cent. to some much lower figure.

Tests were made on specimens cut from electrode A weld metal deposited on plates "padded" with electrode B weld metal (lining about $\frac{1}{8}$ in. thickness). The results are reported in Table XI, and in Fig. 13 the ductility values are compared with those from electrode A weld metal on untreated plates.

The two curves are similar in shape, padding causing a displacement in the direction of greater ductility. The effect is not very marked, which suggests that the principal impurities responsible for lack of ductility are not derived from the plate metal. The tensile strength is also higher when padded plates are used, and this necessitated a slightly smaller gauge diameter than that shown in Fig. 5(c).

Evidently dilution of the weld metal with plate metal has no marked effect but causes a slight loss of ductility.

(j) Ductility of Two Core Wires and Wrought Mild Steel

Small specimens were cut for test from the core wires of 8-gauge electrodes A and B. The results are reported in Table XII and the ductility values are plotted in Fig. 14 where the corresponding values for the respective weld metals are included for comparison. The ductility for the core wire is in general much higher than that of the corresponding weld metals. The values for reduction in area are higher, for testing temperatures in the range 800-1100 deg. C., in the electrode A core wire, though the reverse is the case for the respective weld metals. It appears that low ductility in the weld metals in this temperature range is a result of melting during the welding process, though it should be remembered that the composition of the weld metal is partly controlled by the electrode coating.

The material of core wires is wrought mild steel, generally a rimming steel. For comparison tests have been made on some rolled steel—steel 1—the results being reported in Table XIII, and the ductility values included in Fig. 14. Ductility values are even higher with this steel in the same temperature range, despite a relatively high sulphur content (0·070-0·073 per cent.).

(k) Tensile Strength of Weld Metal and Wrought Mild Steel

In these investigations the main emphasis was on ductility though tensile strength was recorded. In Fig. 15 two curves are plotted for electrode A and electrode B weld metal; they show the same trend—a progressive decay of strength with increasing temperature. Some relatively high values were obtained in the critical range 900-1000 deg. C. for electrode B weld metal. Tensile strength values for wrought mild steel are included for comparison.

Around 900 deg. C. the values for tensile strength are somewhat higher than published values for cast mild steel. Dupuy[6], for example, found a strength of 4·3 tons per sq. in. at 900 deg. C. declining to 2·3 tons per sq. in. at 1100 deg. C. for a mild steel containing 0·15 per cent. carbon. This lower strength is explained by the smaller strain rate which he used (0·002 per second). At higher temperatures, Hall[5] found a maximum tensile strength of 1·5 tons per sq. in. at 1300 deg. C., falling to 0·9 tons per sq. in. at 1400 deg. C., for a mild steel containing 0·10 per cent. carbon. Here the straining rate is more comparable (0·053 per second, compared with 0·02 per second in the present investigation) and the figures are in good agreement with the strength values obtained for weld metal.

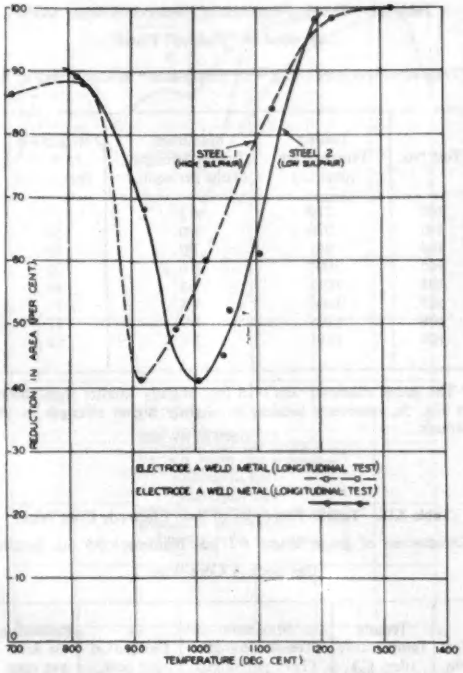
STEEL 1 (HIGH SULPHUR)
STEEL 2 (LOW SULPHUR)
REDUCTION IN AREA (PER CENT)
ELECTRODE A WELD METAL (LONGITUDINAL TEST)
ELECTRODE A WELD METAL (LONGITUDINAL TEST)
TEMPERATURE (DEG. CENT.)

Fig. 10. Effect of sulphur content of plate steel on ductility.

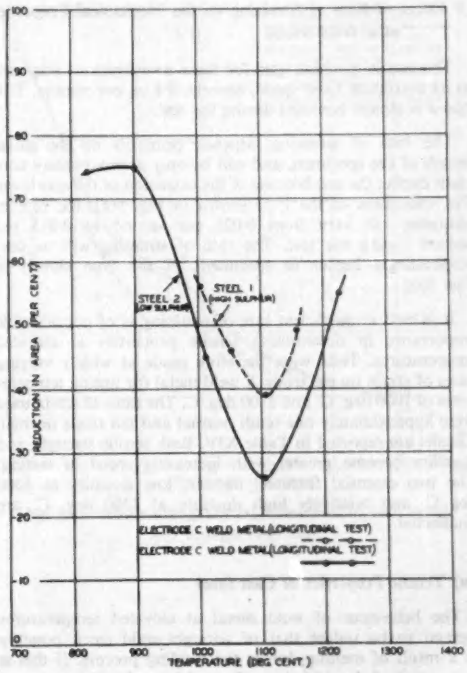
STEEL 2 (LOW SULPHUR)
STEEL 1 (HIGH SULPHUR)
REDUCTION IN AREA (PER CENT)
ELECTRODE C WELD METAL (LONGITUDINAL TEST)
ELECTRODE C WELD METAL (LONGITUDINAL TEST)
TEMPERATURE (DEG. CENT.)

Fig. 11. Effect of sulphur content of plate metal on ductility.

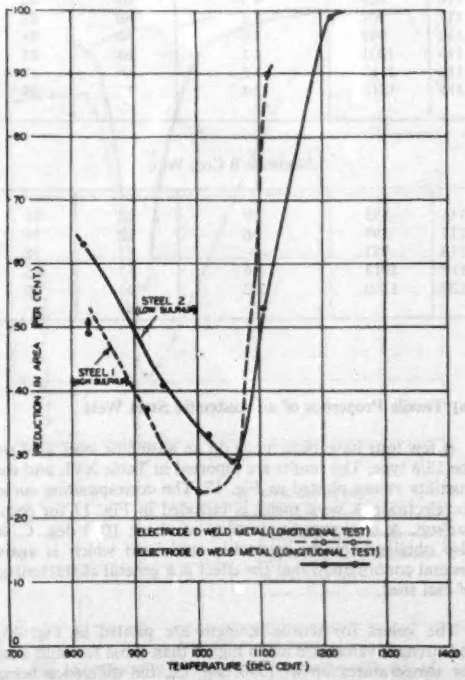
STEEL 2 (LOW SULPHUR)
STEEL 1 (HIGH SULPHUR)
REDUCTION IN AREA (PER CENT)
ELECTRODE D WELD METAL (LONGITUDINAL TEST)
ELECTRODE D WELD METAL (LONGITUDINAL TEST)
TEMPERATURE (DEG. CENT.)

Fig. 12. Effect of sulphur content of plate metal on ductility.

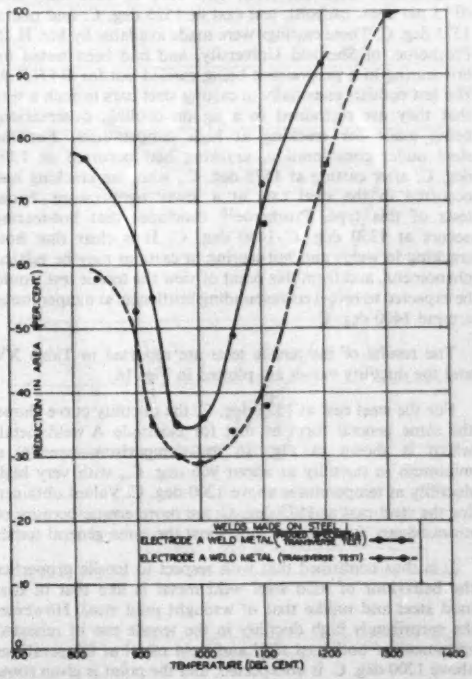
WELDS MADE ON STEEL 1
ELECTRODE A WELD METAL (LONGITUDINAL TEST)
ELECTRODE A WELD METAL (TRANSVERSE TEST)
REDUCTION IN AREA (PER CENT)
TEMPERATURE (DEG. CENT.)

Fig. 13. Effect of "padded" plates on the ductility of weld metal.

(l) Effect of Rate of Straining on the Mechanical Properties of a Weld Metal

The tensile machine used for these investigations was used at its maximum fixed speed, namely, 0·8 in. per minute. This speed is almost constant during the test.

The rate of straining depends primarily on the gauge length of the specimen, and will be only approximately constant during the test because of the extension of the specimen. For specimens of the type shown in Fig. 5(a), the rate of straining will vary from 0·025 per second to 0·015 per second during the test. The rate of straining will be correspondingly higher in specimens of the type shown in Fig. 5(c).

It is well known[4] that rate of straining is of considerable importance in determining tensile properties at elevated temperatures. Tests were therefore made at widely varying rates of strain on electrode A weld metal for testing temperatures of 1000 deg. C. and 1300 deg. C. The rates of strain used were approximately one-tenth normal and ten times normal. Results are reported in Table XIV. Both tensile strength and ductility become greater with increasing speed of testing. The two essential features, namely, low ductility at 1000 deg C. and relatively high ductility at 1300 deg. C. are unaffected.

(m) Tensile Properties of Cast Steel

The behaviour of weld metal at elevated temperatures seemed to be unlike that of wrought mild steel, possibly as a result of melting during the welding process. If this is true cast steel should behave like weld metal.

Specimens were cut from two bars of cast mild steel (0·15 per cent. carbon), one cast at 1525 deg. C. and one at 1575 deg. C. These castings were made available by Mr. H. T. Protheroe, of Sheffield University, and had been tested for hot-tearing in a programme being carried out for B.I.S.R.A. His test consists essentially in casting steel bars in such a way that they are restrained in a jig on cooling, observations being made for cracking at high temperatures. For the steel under consideration, cracking had occurred at 1390 deg. C. after casting at 1575 deg. C., while no cracking had occurred in the steel cast at a lower temperature. From tests of this type, Protheroe[10] concludes that hot-tearing occurs at 1350 deg. C.-1450 deg. C. It is clear that hot-cracking in welds and hot-tearing in castings may be related phenomena, and from this point of view the tensile test would be expected to reveal corresponding brittleness at temperatures around 1400 deg. C.

The results of the tensile tests are reported in Table XV and the ductility values are plotted in Fig. 16.

For the steel cast at 1525 deg. C. the ductility curve shows the same general form as that for electrode A weld metal, which is shown in Fig. 16 for comparison—namely, a minimum in ductility at about 906 deg. C., with very high ductility at temperatures above 1200 deg. C. Values obtained for the steel cast at 1575 deg. C. are more erratic because of unsoundness, but even so they show the same general trend.

It is thus confirmed that with respect to tensile properties the behaviour of mild steel weld metal is like that of cast mild steel and unlike that of wrought mild steel. However, the surprisingly high ductility in the tensile test of reheated specimens of both cast steel and weld metal at temperatures above 1200 deg. C. is unexpected, and the point is given some attention in later discussion.

Table XI. Tensile Properties of Electrode A Weld Metal Deposited on "Padded" Plates

(Transverse specimens (Fig. 4b); dimensions* as shown in Fig. 5c)

Test No.	Testing Temperature (deg. C.)	Maximum Tensile Strength (Tons per sq.in.)	Reduction in Area (per cent.)
102	819	6·3	77
103	926	6·0	55
104	961	7·0	35
105	1004	6·6	36
106	1053	5·4	49
107	1104	4·3	73
108	1105	3·9	67
109	1195	3·1	92

* The gauge diameter was 0·18 ins., slightly smaller than shown in Fig. 5c, necessary because of slightly higher strength in the deposit.

Table XII. Tensile Properties of Two Electrode Core Wires

(Dimensions of gauge length 0·1 ins. diameter × 0·5 ins. length)

Electrode A Core Wire

Test No.	Testing Temperature (deg. C.)	Maximum Tensile Strength (Tons per sq.in.)	Elongation per cent.	Reduction in Area per cent.
110	829	4·5	69	80
111	901	5·6	69	85
112	949	5·0	69	88
113	1003	4·5	68	87
114	1113	3·1	68	97
115	1212	2·4	73	99

Electrode B Core Wire

116	835	3·9	82	81
117	898	3·6	82	76
118	952	—	63	78
119	1013	4·6	62	75
120	1110	3·2	94	99

(n) Tensile Properties of an Austenitic Steel Weld

A few tests have been made on an austenitic steel weld on the 18/8 type. The results are reported in Table XVI, and the ductility values plotted in Fig. 17. The corresponding curve for electrode A weld metal is included in Fig. 17 for comparison. A minimum in ductility at about 1000 deg. C. is also obtained for the austenitic steel weld which is again general confirmation that the effect is a general characteristic of cast steel.

The values for tensile strength are plotted in Fig. 15; the strength values are much higher than those for mild steel for temperatures up to 1300 deg. C., the difference being more marked at the lower temperatures.

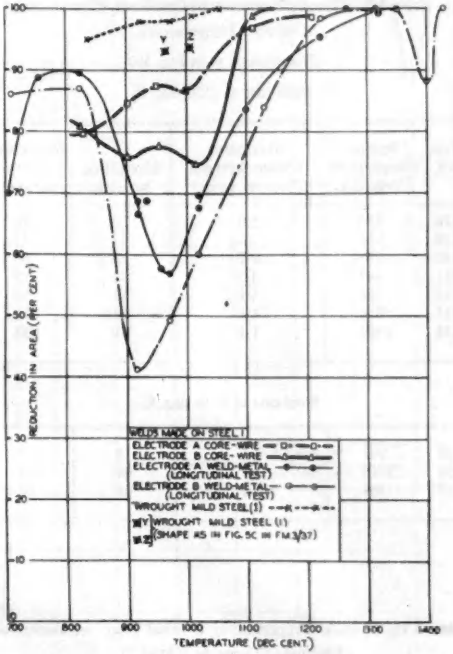
REDUCTION IN AREA (PER CENT)
TEMPERATURE (DEG. CENT)
WELDS MADE ON STEEL 1
ELECTRODE A CORE-WIRE
ELECTRODE B CORE-WIRE
ELECTRODE A WELD-METAL (LONGITUDINAL TEST)
ELECTRODE B WELD-METAL (LONGITUDINAL TEST)
WROUGHT MILD STEEL (1)
WROUGHT MILD STEEL (1)
SHAPE AS IN FIG. 5C IN FM 3/37

Fig. 14. Ductility of two weld metals and of their respective core wires.

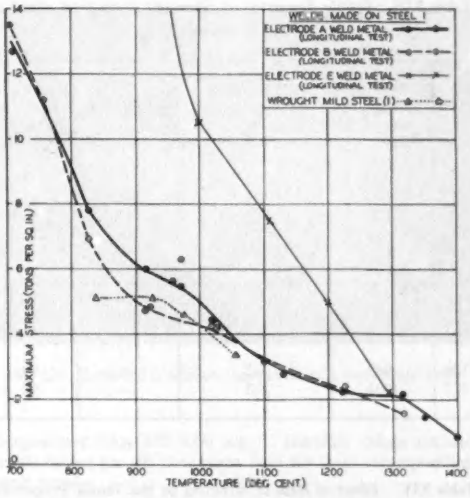
WELDS MADE ON STEEL 1
ELECTRODE A WELD METAL (LONGITUDINAL TEST)
ELECTRODE B WELD METAL (LONGITUDINAL TEST)
ELECTRODE E WELD METAL (LONGITUDINAL TEST)
WROUGHT MILD STEEL (1)
MAXIMUM STRESS (TONS PER SQ. IN.)
TEMPERATURE (DEG. CENT)

Fig. 15. Tensile strength (maximum stress) of weld metal and wrought mild steel.

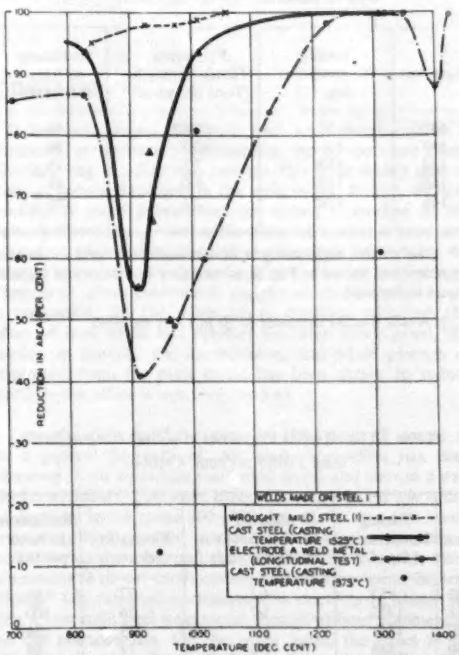
REDUCTION IN AREA (PER CENT)
TEMPERATURE (DEG. CENT)
WELDS MADE ON STEEL 1
WROUGHT MILD STEEL (1)
CAST STEEL (CASTING TEMPERATURE 1529°C)
ELECTRODE A WELD METAL (LONGITUDINAL TEST)
CAST STEEL (CASTING TEMPERATURE 1573°C)

Fig. 16. Ductility of weld metal compared with that of wrought steel and cast steel.

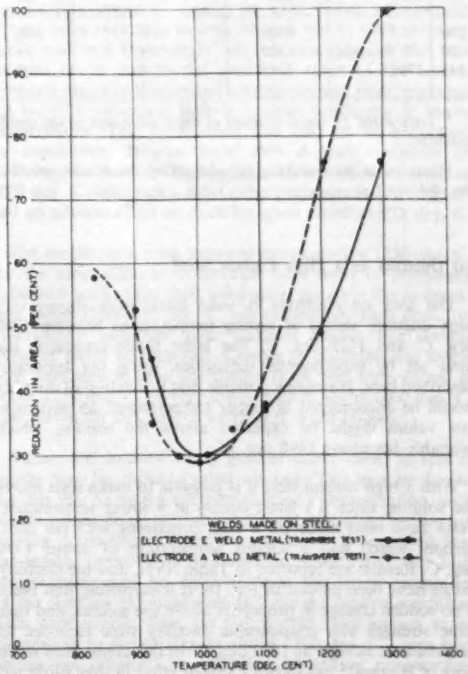
REDUCTION IN AREA (PER CENT)
TEMPERATURE (DEG. CENT)
WELDS MADE ON STEEL 1
ELECTRODE E WELD METAL (TRANSVERSE TEST)
ELECTRODE A WELD METAL (TRANSVERSE TEST)

Fig. 17. Ductility of austenitic steel weld.

Table XIII. Tensile Properties of Wrought Mild Steel (Steel 1)

(Dimensions as shown in Fig. 5b)

Test No.	Testing Temperature (deg. C.)	Maximum Tensile Strength (Tons per sq.in.)	Elongation per cent.	Reduction in Area per cent.
121	838	5·1	51	95
122	923	5·1	57	98
123	973	4·6	47	98
124	1010	3·9	88	99
125	1057	3·4	59	100
	(Dimensions as shown in Fig. 5c)			
126	963	6·2	—	93
127	1004	5·2	—	94

Table XIV. Effect of Rate of Straining on the Tensile Properties of Weld Metal (Electrode A/Steel 1)

(Transverse specimens (Fig. 4b); dimensions as in Fig. 5c)

Test No.	Testing Time (Seconds)	Testing Temperature (deg. C.)	Maximum Tensile Strength (Tons per sq.in.)	Reduction in Area (per cent.)
138	2·5*	1001	8·8	64
29	25 (normal)	1000	5·1	29
139	225†	1007	3·9	28
140	3*	1302	4·8	100
34	28 (normal)	1307	1·8	99·5
141	270†	1318	1·4	90

* Tests made by rapid rotation of the hand-wheel of the tensile machine.

†Tests made by switching on and off at the lowest speed of the motor.

(o) Ductility of a High Carbon Steel

The tests on electrode A weld metal have shown very high ductility values at testing temperatures between 1200 deg. C. and 1425 deg. C. The latter figure represents the limit set by experimental difficulties, using the apparatus described here. It remains possible that low values of ductility would be encountered at higher temperatures. In particular low values might be expected above the solidus, which probably lies above 1490 deg. C.

With a high carbon steel it is possible to make tests above the solidus, since the latter occurs at a lower temperature. Tests have been made on a steel containing 0·85 per cent. carbon, which had a solidus temperature of about 1350 deg. C. Results are reported in Table XVII, and the ductility values have been plotted in Fig. 18. It is surprising that there is no sudden change in properties above the solidus, and that some strength and considerable ductility were recorded at temperatures as high as 1400 deg. C. In this connection some work of Hughes[11] has shown a similar effect in steel subjected to twisting at temperatures above the solidus.

Table XV. Tensile Properties of Cast Steel, Cast at Two Different Temperatures

(Dimensions as in Fig. 5b)

Test No.	Testing Temperature (deg. C.)	Maximum Tensile Strength (Ton per sq.in.)	Elongation per cent.	Reduction in Area per cent.
	Steel cast at 1550 deg. C.			
128	832	5·0	70	94
129	914	—	36	55
130	937	4·1	28	66
131	947	3·7	54	77
132	966	5·1	36	50
133	1010	4·1	60	94
134	1309	1·4	84	100
	Steel cast at 1750 deg. C.			
135	941	4·1	8	12
136	1010	4·1	61	81
137	1309	1·3	84	61

Table XVI. Tensile Properties of a Weld from an Austenitic Electrode (Electrode E/Steel 1)

(Transverse specimens (Fig. 4b); dimensions of gauge length 0·13 in. diameter* × 0·125 in. length)

Test No.	Testing Temperature (deg. C.)	Maximum Tensile Strength (Tons per sq.in.)	Reduction in Area (per cent.)
142	923	20·8†	46
143	1013	10·5	30
144	1108	7·5	37
145	1198	5·0	49
146	1295	2·2	76

* Due to the high strength of the austenitic weld, a smaller diameter than shown in Fig. 5c is necessary to ensure that fracture occurs in the weld.

† A still smaller diameter (0·10 in.) was required.

Table XVII. Tensile Properties of a High Carbon Steel

Steel 3 (0·85 per cent. Carbon)

Test	Testing Temperature (deg. C.)	Maximum Tensile Strength (Tons per sq.in.)	Elongation per cent.	Reduction in Area per cent.
147	955	4·7	77	99
148	1302	1·7	76	100
149	1351	1·2	103	100
150	1388	1·0	77	88
151	1397	0·9	24	58

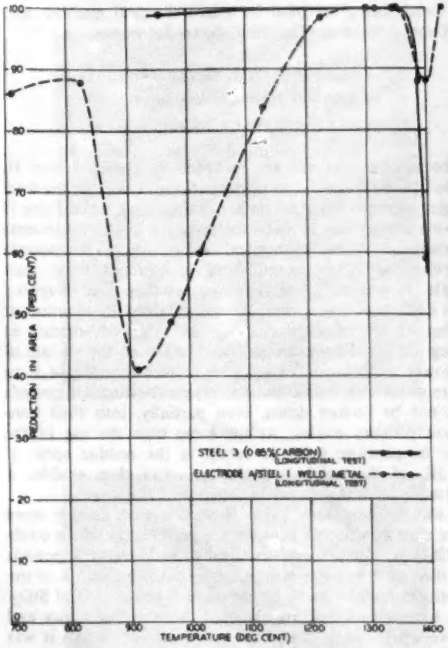
REDUCTION IN AREA (PER CENT)
TEMPERATURE (DEG CENT)
STEEL 3 (0·85% CARBON) (LONGITUDINAL TEST)
ELECTRODE A/STEEL 1 WELD METAL (LONGITUDINAL TEST)

Fig. 18. Ductility of a high carbon steel (0·85 per cent. C.)

Fig. 19. Exploded cracks on the surface of a tensile specimen.

6. DISCUSSION

It has been found that mild steel weld metal exhibits a minimum in ductility somewhere in the temperature range 900-1100 deg. C. For two reasons this is probably due to some structural weakness in the weld metal. Firstly, the low ductility is more pronounced on testing transverse to the welding direction, i.e. across the plane of weakness produced by major segregation. Secondly, annealing presumably by causing homogenisation has a beneficial effect on the ductility. There is no direct evidence to suggest which particular factor is responsible for the minimum in ductility. Although the effect of iron oxide and sulphur has been investigated, the results, in general, are inconclusive, and while pick-up of impurities from the plate metal has been shown to reduce ductility the effect is not very marked.

Low ductility in the range 900-1100 deg. C. seems to be a general property of cast steel. The effect has been observed in an austenitic steel weld metal and also in a cast steel containing 0·2 per cent. carbon. Dupuy[6] found low values of ductility in the range 800-1100 deg. C. for two cast steels, containing 0·15 per cent. carbon and 0·44 per cent. carbon, and Piwowarski[7] obtained similar results for two cast steels containing 0·18 per cent. carbon and 0·44 per cent. carbon. Hodge[8] has reported a minimum in ductility at about 900 deg. C. for mild steel weld metal, though without commenting on the phenomenon. On the other hand, the effect is not observed in wrought steel. It has been shown that high ductility values are obtained in wrought mild steel over the temperature range 840-1050 deg. C. Ductility values are also much higher for the core wires than for their corresponding weld metals.

The range of low ductility for temperatures 900-1100 deg. C. is probably not connected with hot-cracking. The electrodes tested may be placed in the other D, C, B, A, for increasing susceptibility to hot-cracking, and in the order B, A, D, C, for increasing susceptibility to low ductility in the range 900-1100 deg. C. In addition, the use of an excessive welding current, which is known to promote hot-cracking, has a beneficial effect on ductility in this temperature range.

On raising the testing temperature from 1100-1200 deg. C. the ductility improves rapidly to give values approaching 100 per cent. reduction in area. Similar results were obtained by Dupuy[6] and Piwowarski[7] on cast steel. At first this was thought to be due to the annealing effect of the testing temperature, i.e. diffusion and homogenisation were removing the harmful structural defects causing brittleness at lower temperatures. This explanation was only partly confirmed by experiment. It was found that a prior treatment at 1340 deg. C. increased the ductility on subsequent testing at 1000 deg. C., although a short prior treatment at 1200 deg. C. had an adverse effect on ductility when tested at 925 deg. C.

The results for testing temperatures exceeding 1250 deg. C. are the most difficult to correlate with those of previously published work. Mild steel weld metal tested in the temperature range 1250-1425 deg. C. has exceedingly high ductility. Piwowarski[7] obtained quite different results. For several different steels he obtained a curve of characteristic shape with reduction in area descending from very high values at about 1250 deg. C. to very low values at about 1400 deg. C. The reason for this lack of agreement is not known.

Values for ductility are in general rather lower in Hall's[5] results than for those of other workers. This may be due to the fact that he used a different method of investigation, with tensile testing being carried out on cast specimens as they are cooling down from the molten condition. It suggested that the tensile properties of cast steel on reheating at very high temperatures may be different from the tensile properties of the steel on its initial cooling from the molten condition. This may explain why, on testing cast steel known to be susceptible to hot-tearing at about 1390 deg. C., very high values are obtained on reheating to testing temperatures exceeding 1300 deg. C.

Weld metal has been tested at temperatures up to 1425 deg. C., which represents the limit set by experimental difficulties with the apparatus described here. The solidus temperature lies well above this for mild steel (1490 deg. C.), but it has been found possible to test above the solidus for a high carbon steel (1350 deg. C.). In this case some strength and considerable ductility were found at temperatures 50 deg. in excess of the solidus temperature.

APPENDIX 1

Subsidiary Failure in Weld Metal Tensile Specimens

In one or two instances an unusual effect was observed on fractured all-weld-metal specimens. Near the main fracture a small crack would appear, on both sides of which the metal was distorted outwards (Fig. 19). The effect was only observed for testing temperatures around 1100 deg. C.

It may be that gas under pressure is responsible for the effect, though a second possible explanation cannot be dismissed, i.e. that uneven deformation in some cases sets up high tensile stresses in the surface layers.

APPENDIX 2

DETERMINATION OF THE PERCENTAGE AND CONSTITUTION OF THE OXIDE INCLUSIONS IN THREE SAMPLES OF MILD STEEL WELD METAL

The analyses were carried out in connection with the investigation into the tensile properties of mild steel weld metal at high temperatures being undertaken by the staff of the British Welding Research Association.

Samples of weld metal deposits from three different electrodes were forwarded to the N.P.L. and examined by the alcoholic iodine method, the residues, after solution of the metal, being analysed by micro-chemical methods and by X-ray diffraction. The three electrodes were

A. to BEAMA/IOW Classification E.217
C. to BEAMA/IOW Classification R.416
D. to BEAMA/IOW Classification E.537

The results obtained are recorded in Tables I and II. Table I shows the amounts of the various oxides and the total oxygen, expressed as a percentage of the metal, while Table II shows a comparison between the principal oxide constituents as determined by micro-chemical analysis and the compounds identified by X-ray examination of residues from each sample. It will be noted that two residues were prepared from each weld metal sample, one obtained by solution at 65 deg. C. for chemical analysis, the other by solution at 30 deg. C. for X-ray examination. The reason for the use of the lower temperature of solution in the second case is to ensure as far as possible that the oxygen-bearing compounds shall not be broken down, even partially, into their constituent primary oxides. At the same time the use of the lower temperature tends to retain in the residue some, if not all, of the sulphide inclusions, and thus enables a qualitative identification of their nature to be made.

It will be seen from Table II that in each sample there was a close correlation between the percentages of the oxide constituents determined chemically and the compounds identified by X-ray examination. The oxide inclusions in the deposit from electrode A contain a high proportion of SiO_2. Such inclusions would be expected to be rather glassy and to give a very weak X-ray diffraction pattern, which it was not possible to identify.* The presence in the sample of sulphur as MnS was, however, firmly established.

* The inability to identify the inclusions may have been because they contained significant amounts of TiO_2 and might therefore be expected to consist of a complex titanosilicate, for which no X-ray reference data are available.

Table I. to Appendix 2. Analyses of Alcoholic Iodine Residues from Welds at 65 deg. C.

Electrode BEAMA/IOW Classification	Code	Oxide in the Residue and Equivalent Oxygen Value Expressed as a Percentage of the Weld														Total Oxygen Per Cent Calculated
		SiO_2		FeO		Al_2O_3		MnO		Cr_2O_3		P_2O_5		TiO_2		
		Oxide	Oxygen	Oxide	Oxygen	Oxide	Oxygen	Oxide	Oxygen	Oxide	Oxygen	Oxide	Oxygen	Oxide	Oxygen	
E.217	A	0·088	0·047	0·013	0·003	0·005	0·002	0·084	0·019	0·005	0·002	0·004	0·002	0·018	0·007	0·082
R.416	C	0·082	0·044	0·009	0·002	0·002	0·001	0·164	0·037	0·001	0·0003	0·017	0·009	0·004	0·002	0·095
E.537	D	0·003	0·001	0·700	0·155	0·003	0·001	0·010	0·002	0·003	0·001	0·005	0·003	—	—	0·163

Table II to Appendix 2. Comparison between Analytical and X-ray Examination of Residues

Electrode BEAMA/IOW Classification	Principal Oxide Constituents of the Residue at 65 deg. C.			Compounds Identified by X-ray Examination of the Residue obtained at 30 deg. C.
	FeO per cent.	MnO per cent.	SiO_2 per cent.	
E.217	6	39	41 TiO_2 8	Small quantity of an unidentified compound + MnS
R.416	3 P_2O_5 6	59	29	2(Mn, Fe)O . SiO_2 .
E.537	97	1·0	0·4	FeO; small quantity Fe_3O_4 . + FeS (probable)

Fig. 20. (×4700)

Fig. 21. (×4300)

Fig. 22. (×4300)

Fig. 23. (×4000)

Figs. 20-23. Structures found in electrode A weld metal.

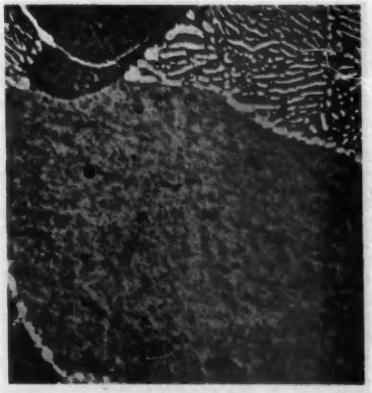

Fig. 24. (×4000)

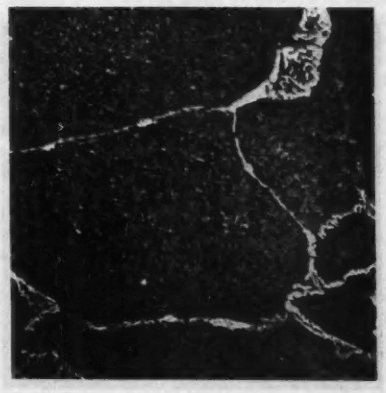

Fig. 25. (×4000)

Figs. 24-25. Structures found in electrode B weld metal.

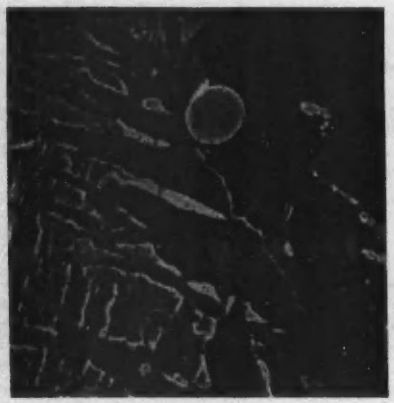

Fig. 26. (×4400)

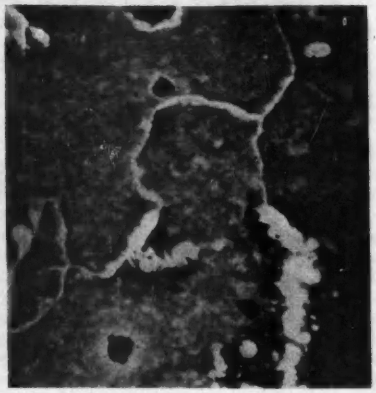

Fig. 27. (×5300)

Figs. 26-27. Structures found in electrode B weld metal.

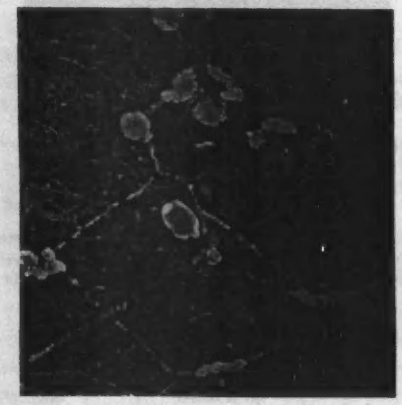

Fig. 28. (×4400)

Fig. 29. (×4400)

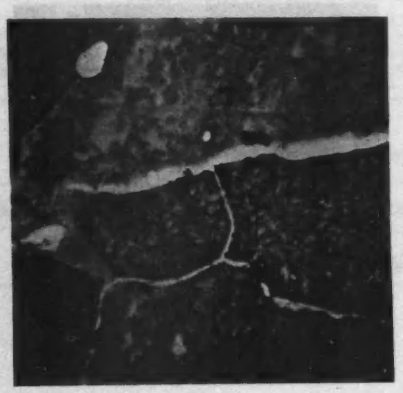

Fig. 30. (×4300)

Fig. 31. (×4400)

Figs. 28-31. Structures found in electrode D weld metal.

The sample from electrode C gave a much stronger X-ray diffraction pattern, the spacings in which were between those for tephroite ($2MnO \cdot SiO_2$) and fayalite ($2FeO \cdot SiO_2$) indicating that the inclusions consisted of tephroite in which a small portion of the manganese had been replaced by iron. In Table II this is indicated by the use of the formula $2(Mn, Fe)O \cdot SiO_2$. No indication of the presence of a sulphide was found in the X-ray photograph of this residue.

Electrode D gives a deposit in which the oxygen is present essentially as iron oxide. This was confirmed by the X-ray examination. The presence of a small amount of Fe_3O_4 associated with the FeO may be noted. Other lines on the X-ray photograph indicated that the sulphur in this deposit is probably present combined with iron in the form of FeS.

APPENDIX 3

EXAMINATION OF WELD METAL STRUCTURES UNDER THE ELECTRON MICROSCOPE

In the course of investigations into the problem of hot-cracking in mild steel weld metal, some attention was given to the examination of the weld metal at high magnification under the light microscope. It was found that in the throat of the weld, i.e. in the region where hot-cracking is liable to occur, the grain boundaries appeared to be outlined with some constituent. This effect became more definite in weld metal liable to hot-cracking, but was in all cases on a very fine scale and could not be made out very clearly even at the limit of resolution of the light microscope, at a magnification of, say, 1,500 times.

It was felt that the effect might be better studied at even higher magnifications using the electron microscope. An investigation of this sort was kindly undertaken at the B.N.F.M.R.A. laboratories.

Accordingly, sections through three weld metals were submitted to them for examination:

Electrode A—A general purpose electrode, particularly susceptible to hot-cracking.

Electrode B—A general purpose electrode, not particularly susceptible to hot-cracking.

Electrode D—An oxide coated electrode, not at all liable to the defect of hot-cracking.

These electrodes are as used in the investigation on the mechanical properties at elevated temperatures, and the analyses of the weld deposits, together with the B.E.A.M.A. classification numbers for the electrodes, may be found in the section on "Materials" in the main body of the paper.

For each weld metal a replica was taken in the region of the throat of the weld, where hot cracking is most liable to occur. Examination under the electron microscope showed that, even in this small area, the structure was subject to wide variations. It was difficult, therefore, to cover these variations with a few typical photographs. In all, 52 photographs were taken from the replicas of the three weld specimens. Only 12 of these have been used in the present instance to illustrate particular points. Some of the written comment here must be taken as deriving from the experience gained by a general visual survey of the replicas under the microscope.

The technique used at the B.N.F.M.R.A. in obtaining the photographs was as follows:

The weld specimens were prepared in the usual way, except that the final polish was given using diamond powder. This technique has been described by E. C. W. Perryman.* They were then etched for 10-20 seconds in 3 per cent. nital solution. After cleaning the etched specimens by means of a collodion film, which was discarded, a thin Formvar replica film was applied. This was strengthened by a backing film of collodion and the double film was stripped under water. The backing film was subsequently dissolved, leaving the Formvar replica for examination.

Selected photographs, four from each replica, are given in Figs. 20-31, and illustrate the more interesting features observed. The magnifications used were in the range 4000-5000 times.

In the case of electrode A weld metal, which is specially liable to hot-cracking, the structures were in general rather coarse. For instance, Fig. 20 and, to a less extent, Fig. 21, show that the structure of the binary carbide entectoid is rather coarse by comparison with that from the other weld metals. It is more significant, however, that the grain boundaries are usually heavily outlined as shown in Fig. 22, though occasionally this feature is a little less pronounced (see Fig. 23).

The structures found in electrode B weld metal are much finer, Figs. 24 and 25 being typical. Occasionally coarser structures are found as shown in Figs. 26 and 27.

With electrode D weld metal, known to be free from hot cracking, the grain boundaries are much fainter and not always continuously outlined with any constituent. Figs. 28, 29 and 30 are typical. The binary carbide eutectoid is very fine and is small in amount (see Fig. 31), as would be expected since the carbon content is lower in this case.

Electrode D weld metal was found to contain the greatest quantity of non-metallic inclusions, though this is not shown in the photographs. The effect is in agreement with the results of the analyses reported in Appendix 2, which show that this weld metal had the highest iron oxide and total oxygen content.

Presumably the main constituent found on the grain boundaries is iron carbide, though it may be contaminated by traces of oxides and sulphides. Of course, any constituent of low melting point on the grain boundaries is suspect in connection with the problem of hot-cracking. It is interesting to note that, with the three weld metals examined, the extent to which they are susceptible to hot-cracking seems to bear some relation to the amount of precipitated constituent on the grain boundaries.

* E. C. W. Perryman, *Journ. Inst. Metals*, March, 1950, p. 61.

ACKNOWLEDGMENTS

Acknowledgments are gratefully made to:—

The British Non-ferrous Metals Research Association, for taking photographs of the structures of three weld metals with the electron microscope.

The National Physical Laboratory, for making the constitutional analysis on weld metal residues, and for making available their report on this work for inclusion as Appendix 2 in the present paper.

Dr. Reeve, for helpful advice and criticism, for making analyses and for supplying steel plate.
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Mr. Hignett, for arranging for the dilatometric investigation of two weld metals.
Mr. Protheroe, for making available some cast steel for tests.

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R.64

Ductility of Mild Steel Welds near the Solidus

By E. C. ROLLASON, Ph.D., M.Sc., F.I.M.*

SYNOPSIS

The results of some simple hot tensile tests on core wire and weld metal show a lowering of ductility at 1250-1280 deg. C. Welds graded according to this criteria are in correct order as regards hot-cracking during welding. Increase of manganese in one type of electrode is shown to maintain hot ductility to a higher temperature.

INTRODUCTION

Hot-tearing of castings has been well known for a long time, and in welds a similar feature, known as hot-cracking, can occur. Whilst it is possible to design castings to minimise restrictions which would accentuate hot-tearing, it is almost impossible to avoid restrained joints in welded fabrication. Thus it is essential that electrodes should be capable of making welds free from hot cracking. Work with the Murex hot-crack machine, in which a single bead is strained during deposition by external force, had indicated that cracking occurred near the freezing temperature of the weld metal. Consequently, it was thought desirable to measure the change in ductility of mild steel weld metal at temperatures exceeding 1100 deg. C. This work was carried out in 1944 and relatively simple apparatus was used. The results, however, indicated a drop in ductility in the region of 1300 deg. C., and it was suggested to the R.F.M. Committee of B.W.R.A. in December, 1945, that in studying the causes of hot-cracking it would be worth while to determine the mechanical properties of weld metal near the solidus. As a result, Winterton and Ball have carried out some excellent work using refined apparatus, but the results failed to indicate any drop in ductility at 1200-1400 deg. C. It was thought desirable, therefore, to give a brief account of the early tests which draw attention to rate of heating as one factor which may be considered in future work.

APPARATUS

The simple form of hot tensile machine is shown in Fig. 1. This consisted of an upper fixed grip to take specimen 4 in. long with a gauge diameter of 0·191 in. The lower movable grip was attached to a simple lever system by means of which a load of 80 lb. could be applied suddenly to the specimen by rotating an eccentric cam. Very rapid failure ensued minimising the effect of creep and reduction of area measurements were used to indicate ductility, i.e.

$$\frac{(d_1 - d_2)^2}{d_1} \text{ 100 per cent.}$$

Resistance heating was used, the specimen being in the secondary of 2-volt transformer delivering up to 200 amps. The rate of heating to 1400 deg. C. was therefore a matter of seconds. To minimise oxidation a chamber, fitted with a

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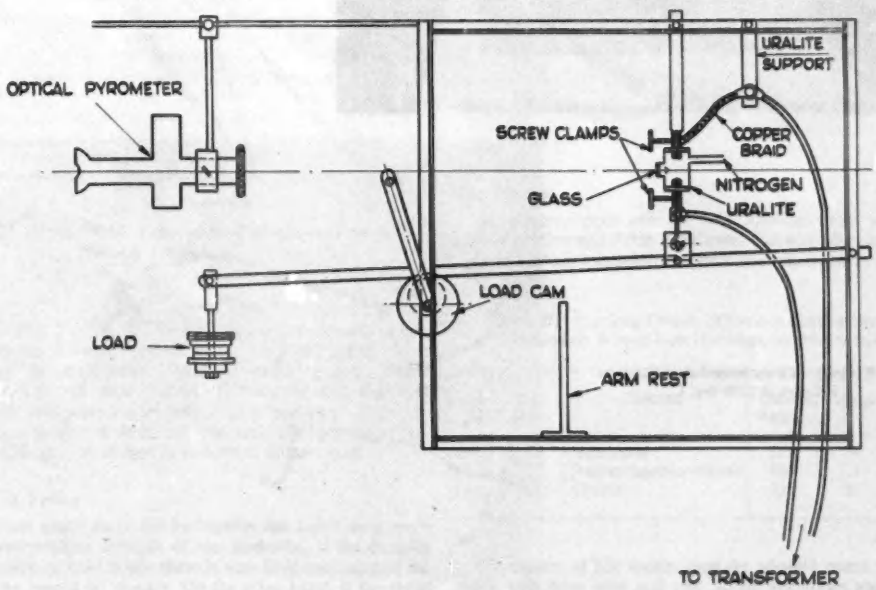


Fig. 1. Hot tensile tester.

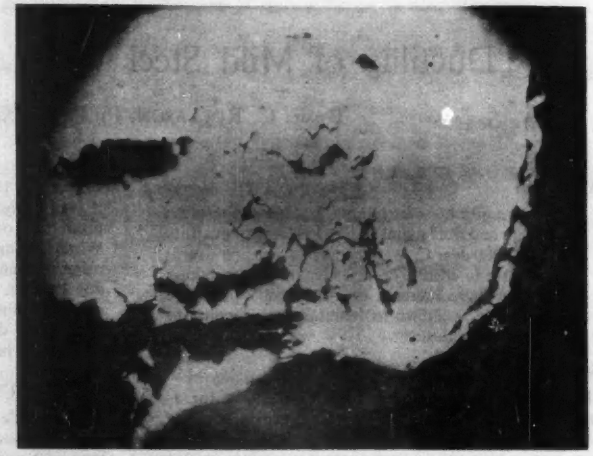


Fig. 3 (*right*). General collapse in FR wire at 1290 deg. C.

×20

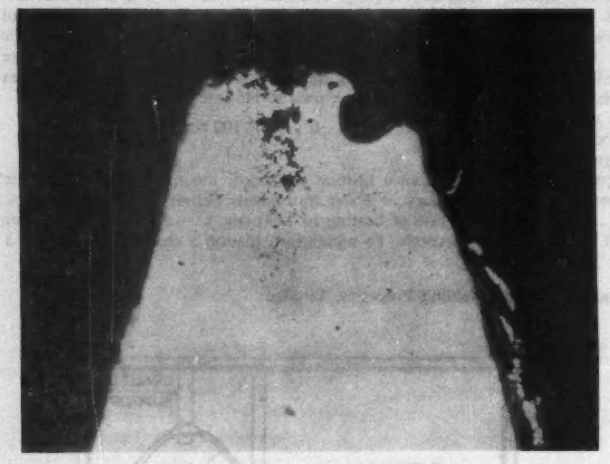


Fig. 4 (*left*). Fracture of RR wire at 1290 deg. C.

×30

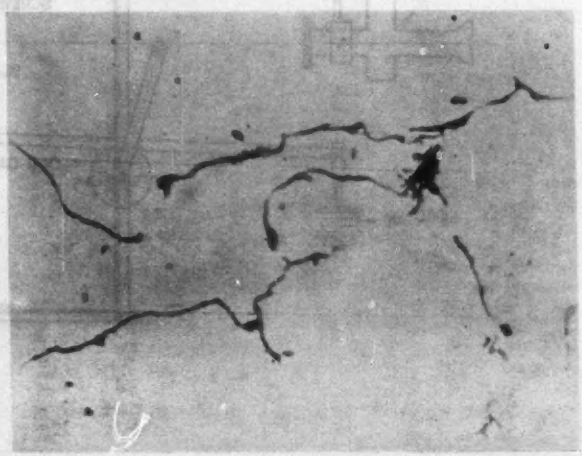


Fig. 5 (*right*). Grain boundary collapse in FR wire at 1290 deg. C.

×70

glass observation window, surrounded the specimen and oxygen free nitrogen was used as a protective atmosphere, escaping around the lower grip. Temperature measurements were made by means of an optical pyrometer sighted on the wire specimen via the glass window. The readings were checked with a Pt-Pt/Rd couple on the specimen with reasonable agreement of ±10 deg. C.

RESULTS

Core Wire

Tests have been made both on core wires and on weld metal deposited from these core wires after coating with a single batch of flux. Typical results are given in Fig. 2 and analyses are given in Table I.

Table I. Composition of Core Wires and Weld Metal (R227 Type)

	Percentage					Hot Cracking
	C	Mn	Si	S	P	
F.R. Wire ..	0·13	0·39	0·01	0·034	0·049	
F.W. Weld	0·12	0·52	0·15	0·022	0·072	Bad
R.R. Wire ..	0·11	0·40	0·015	0·041	0·024	
R.W. Weld	0·10	0·53	0·16	0·028	0·042	Good

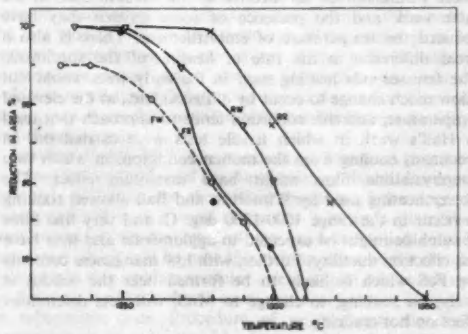


Fig. 2. Hot ductilities of two wires—FR, RR—and the welds from them with R227 coating.

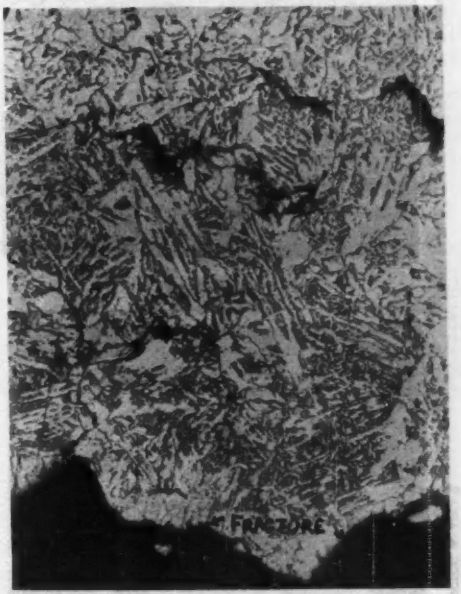
From Fig. 2 it will be seen that the two wires begin to lose ductility at different temperatures, and this difference is reflected in the ductility and hot-cracking (on Murex Machine) of the weld metals. The ductility of the weld metal is somewhat lower than that of the wire. Since the coating is similar in each case, the variation in hot-cracking properties must be sought in variations in the wires.

Mode of Failure

The test specimen in the hot tensile test failed as a result of intercrystalline collapse of the austenite. If the ductility of the wire or weld is low there is very little necking and the specimen breaks off quickly. On the other hand, if the metal is ductile at its elevated temperature, necking occurs and the temperature rises before final collapse. The true temperature is, therefore, higher than that obtained in the test.

The temperature at which ductility begins to drop is likely to be reasonably accurate, but the temperatures for low values of reduction of area are higher than those reported.

Fig. 3 shows the general collapse of a wire having poor ductility (FR), while Fig. 4 shows the necking and internal failure of a typical ductile wire. Fig. 5 shows grain boundary cracks in a poor wire. The intergranular cracks in weld FW fractured at 1300 deg. C. are shown in Fig. 6.



×100

Fig. 6. Intergranular cracks in FW weld metal at 1300 deg. C.

The Coating

The effect of poor wire on weld cracking varies with the type of coating and Table II indicates that some flux coatings, e.g. class 2, can minimise the effect to some extent.

Table II. Cracking Criteria of Various Coating Types Extruded on Wire of Low Hot Ductility (Murex m/c)

I.O.W.-B.E.A.M.A.	Coating	Current Amps.	Voltage	Hot Crack Index
Class 5 ..	Iron oxide	215	24	40
Class 4 ..	Iron-manganese silicate	195	25	26
Class 2 ..	Titania	210	21	4

The results of hot tensile tests on all-weld metal samples made with bare wire and two fluxed electrodes are shown in Fig. 7. The E217 type weld metal shows superior ductility

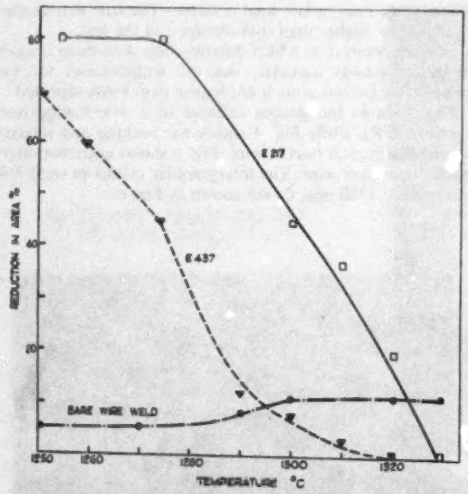


Fig. 7. Hot ductilities of three weld metals.

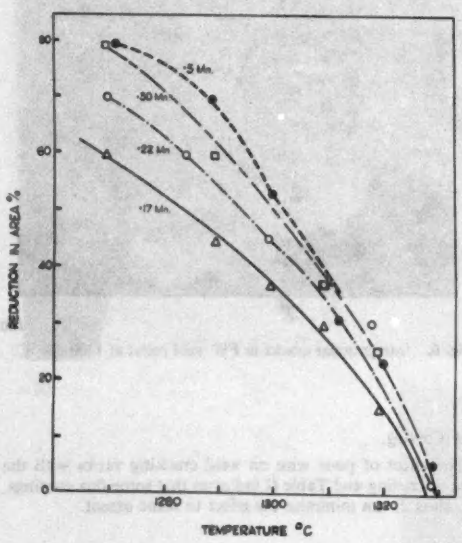


Fig. 8. Effect of manganese addition to weld via coating.

over E437 type which agrees with practical welding experience in which this electrode cracks in a "T" fillet test. This is partly due to high carbon and low manganese contents. The bare wire weld has very low hot ductility and always cracks readily in the Murex hot-cracking machine.

The analyses of the welds in Fig. 3 are:

	C	Mn	S	P	N_2
Bare Wire ..	0·07	0·10	0·022	0·01	0·19
E437	0·16	0·24	0·026	0·05	0·02
E217	0·08	0·50	0·03	0·03	0·02

Although several factors influence the incidence of hot-cracking, it is recognised that elements which form low melting point films at the elevated temperature are pernicious. Sulphur as iron sulphide can readily induce hot-cracking of welds, but the addition of manganese can produce an improvement by forming high melting point MnS. To illustrate this point a series of electrodes were made using the same cast of wire and coatings with varying amounts of ferromanganese in the flux. The hot ductilities are shown in Fig. 8, and it will be observed that manganese additions to the coating of this electrode have beneficial effects as regards hot ductility of the welds.

DISCUSSION

The decrease in ductility of welds is found to start at about 1250 deg. C., although due to lack of refinement in the apparatus the true temperature may be somewhat higher. The lack of agreement between these results and those of Winterton and Ball may be due to either one or both of two differences in experimental procedure. The protective atmosphere would not be so effective as the vacuum used in the later work and the presence of some oxygen may have reduced the temperature of embrittlement. There is also a great difference in the rate of heating of the specimens. The few seconds heating used in the early tests would not allow much change to occur by diffusion, etc., at the elevated temperature, and this condition tends to approach that used in Hall's work in which tensile tests were carried out in specimens cooling from the molten condition, in which case intercrystalline films might have maximum effect. The slower heating used by Winterton and Ball allowed soaking to occur in the range 1000-1200 deg. C. and very fine films of sulphide might be expected to agglomerate and thus have less effect on ductility. Further, with low manganese contents the FeS which is likely to be formed near the solidus is likely, on soaking, to change to MnS, with less deleterious effect on hot-cracking.

This work was carried out in the Research Laboratories of Murex Welding Processes Limited and the practical help of P. Harris is acknowledged.

R.65

An Explanation of Hot-Cracking of Mild Steel Welds

By E. C. ROLLASON, Ph.D., M.Sc., F.I.M. and D. F. T. ROBERTS, B.Sc. (Tech.)*

SYNOPSIS

One explanation of the hot-cracking of mild steel welds is based on the major effect of sulphur and manganese, modified by the minor influences of phosphorus, silicon, carbon and nickel.

INTRODUCTION

Hot cracks in mild steel welds are intercrystalline tears occurring at an elevated temperature, and the surfaces of the crack are "blued" by oxidation. This appearance provides ready recognition from other forms of crack occurring near room temperature.

The cracks generally occur longitudinally in varying lengths in the bead, and sometimes as an extension of a crater crack (Fig. 1). Discontinuous branching cracks occasionally occur at right angles to the ripple marks (Fig. 2). A rarer form of crack occurs transversely (Fig. 3).

Cracking has been observed to develop while the arc is still playing on the crater, and a highly skilled welder can sometimes make a sound deposit from an electrode known to be somewhat susceptible to hot-cracking. This depends on the welder, mainly unconsciously, repairing minute cracks appearing in the semi-molten crater. This would be impossible unless cracks form near the melting point.

Hot cracks generally appear in a zone of relatively low strength which approximates to the throat region of the weld, the last part to solidify. As shrinkage of the cooler parts is occurring simultaneously the centre of the weld is subject to shrinkage stresses which produce plastic flow. In a sound weld the metal has sufficient ductility to flow as contraction takes place. A crack-susceptible weld has insufficient ductility and therefore tears.

Varying degrees of self-imposed strain occurs in practice. In a tee fillet joint some of the contraction of the bead on one side may be added to the self-contraction of the second bead; while in a ring weld around a tube in a plate the contraction of the first part of the bead is applied to the latter part which will be near the melting point of the metal. In multiple ring welds a complex stress system can be set up by the early welds which will cause a critical amount of strain in subsequent ones. Procedure of welding can therefore accentuate or minimise the risk of hot-cracking. Other factors are weld contour, welding current and arc length.

PREVIOUS WORK

Previous work has shown the causes of hot-tearing and hot-shortness of iron and steel to be carbon and sulphur, the latter only being important in hot-shortness since this applies to nominally completely solid material.

Norris[1] has shown that the relationship between manganese and sulphur, with a correction for the oxygen content, will explain the incidence of hot-shortness, due to FeS films. This work disposed of the theories based primarily on the effect of oxygen: certainly, if oxygen were the cause of hot-shortness, welds would be much more susceptible to it, and its elimination would be very difficult.

Hall[2] has shown both the effect of carbon and of sulphur as well as those of other materials, especially phosphorus, on the hot tensile properties of castings at temperatures close

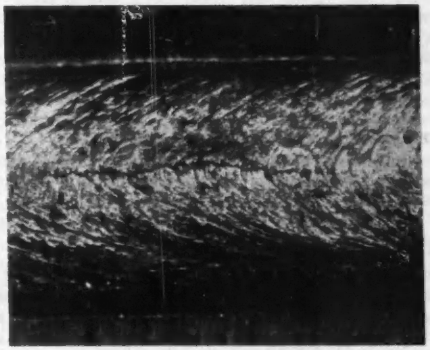


Fig. 1. Longitudinal hot crack.

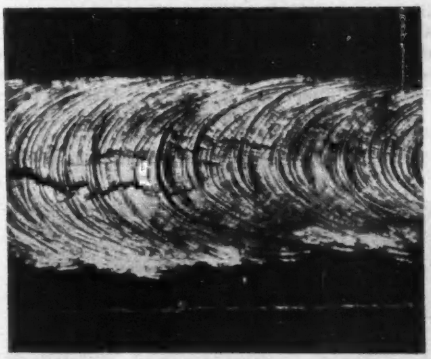


Fig. 2. Branching hot crack.

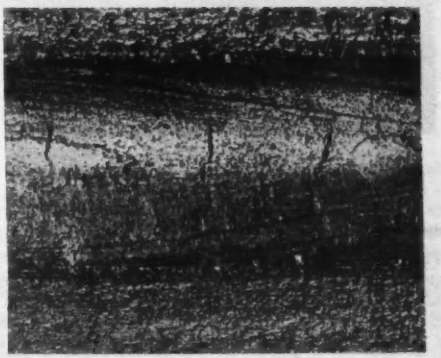


Fig. 3. Transverse hot crack.

* E. C. Rollason, Director of Research, and D. F. T. Roberts, Research Assistant, Murex Welding Processes Limited.

to the solidus. This work is, unfortunately, insufficiently detailed to give a complete account of the effects of S and P, but the effect of carbon is clearly shown and related to the constitutional diagram. It is clear that at over 1400 deg. C. only steels with less than 0·1 per cent. C., approximately, possess any useful ductility. It was also shown that increased S and P, in materials of similar analysis in other respects, caused a lowering of hot ductility.

Reeve[3] has shown that hot-cracking arising from the nature of the plate to be welded is associated with the sulphur pick-up from the plate, and has shown widely differing sensitivities to sulphur pick-up. This work, however, did not sufficiently distinguish between inherent hot-cracking of the weld metal and that due to sulphur pick-up, i.e. did not bring out clearly the amount of cracking obtainable with high quality plate due entirely to the electrode itself.

The importance of sulphur and the minor effect of phosphorus and carbon has been mentioned by Helin and Svantesson.[4]

A HYPOTHESIS

Crystallisation starts at the fused zone of the plate, and if the melt is not agitated by the electrode movement, long columnar crystals develop into the melt. In common with all alloys these crystals are purer than the deposited weld and the residual liquid is enriched in impurities. This concentration of lower melting point alloy occurs partly between the growing crystals and partly ahead of the crystal front, which finally forms an impure region near the throat of the weld.

Weld cracks may therefore be expected to occur mainly in the austenite boundaries (Fig. 4) and the plane between opposing crystal growths. Any element which forms low melting point compounds is, therefore, likely to increase hot shortness. Sulphur is such an element (Fig. 5 shows a film of FeS).

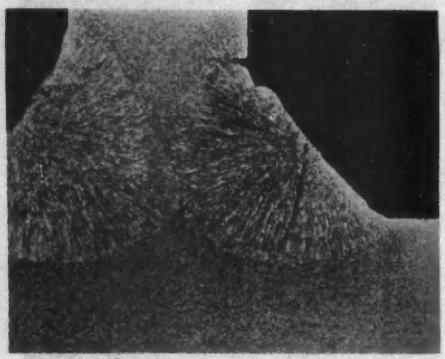


Fig. 4. Internal hot crack.

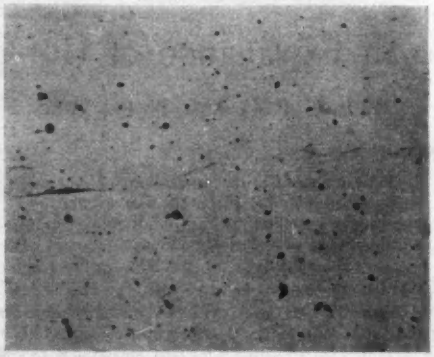


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Fig. 5. Sulphide film in weld metal.

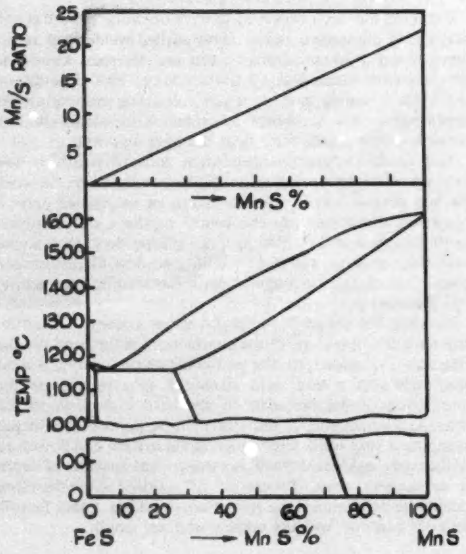

Fig. 6. Equilibrium diagram of the FeS-MnS systems and the relation of amount of MnS to the Mn/S ratio.

Sulphur

For many years sulphur has been recognised as an important factor in hot tearing or cracking. The reason is readily seen from Fig. 6 which gives the melting point of FeS as 1193 deg. C. The presence of traces of the FeS around the austenite boundaries reduces cohesion even at 1200 deg. C. It has been known for many years that the addition of sufficient manganese to a steel improves hot ductility by forming MnS or managnese rich sulphides with melting points above that of steel. MnS becomes increasingly stable as the temperature drops to 900 deg. C., and MnS can also dissolve a large amount of FeS as shown by the solubility curve in Fig. 6. Whiteley[7] has stated that in order to form MnS at the freezing point of steel the ratio of manganese to sulphur should exceed 22. The steel maker, however, often avoids hot tearing trouble even with a ratio of Mn/S=5. In welds, on the other hand, it is desirable to maintain a ratio of 15. Much discussion in the past has been concerned with hot shortness in forgings and it is desirable to consider how the conditions in such an application vary from that found in weld metal.

The steel ingot cools slowly and is not subjected to much restraint and, before rolling, is homogenised to some extent in the soaking pit. As a result manganese has a reasonable chance of combining with sulphur and sulphide films tend to ball-up, in which form they have less effect on the cohesion.

In comparison a weld cools much more rapidly than an ingot and sulphur tends to be retained in solution. This is readily demonstrated by taking sulphur prints of a normal weld and one annealed at 1200 deg. C. The former weld gives a pale print indicating little massive MnS to be attacked by the acid. With rapid cooling therefore, any excess of sulphur over the solubility limit will form FeS due to insufficient time for diffusion processes to occur. Solubility of FeS appears to be approximately 0·3 per cent. at 1250 deg. C.

Reeve has demonstrated the effect of sulphur pick-up from the parent plate. The effect of sulphur from the flux coating is shown as follows:

Electrode	*Amount of Sulphur in Coating*	*Length of Hot Crack*
E 317	Trace	0
	0·04	1½ in.

Effect of sulphur in the wire on the cracking of various types of weld metal is shown in Table I, in which the length of the test specimen was 3 in. The Murex hot crack machine was used.

Table I

Composition of Wire				Length of Hot Crack, Inches			
S	Mn	C	Si	E.517	E.317	E.217	E.645
0·023	0·25	0·08	Tr.	2	1¾	0	0
0·035	0·25	0·08	Tr.	2	1¾	0	0
0·046	0·26	0·08	Tr.	2*	1¾	1	¼

* No cracking in normal service, see later explanation.

DEAD SOFT WELDS

Dead soft mild steel weld metal produced from coatings rich in iron oxide offer, under certain conditions, a tolerance for sulphur without cracking. Up to about 0·06 per cent. sulphur it is considered that the FeS formed is combined with the isolated particles of iron oxide rich inclusions and, therefore, has less effect on boundary weakening. Above about 0·06 per cent. sulphur FeS (or FeS-FeO eutectic) films form and cracking susceptibility increases. In the rutile E.317 type electrode the omission of manganese from the coating gives weld metal with a fairly high resistance to hot-cracking under certain conditions of cooling, these being "soft" weld metals, not "dead soft."

MANGANESE

The addition of manganese to weld metal reduces the amount of FeO inclusions (Sloman[6]), and tends to form (MnFe)S, but from Fig. 4 it will be seen that about 60 per cent. MnS is necessary to raise the melting point of the inclusion to 1500 deg. C. A mixed sulphide containing 25 per cent. MnS has such a low melting point that grain weakening films are still likely to cause hot-cracking.

The first effect of a manganese addition to oxidised weld metal is therefore likely to increase cracking while further additions will reduce cracking. This is in agreement with practical experience in electrode development. In considering the effect of manganese it must be borne in mind that manganese as estimated by the analyst may exist in different forms with varying effects, e.g. MnO, MnS, $2MnOSiO_2$, or Mn. As regards effect on hot cracking, Mn is of prime importance.

PREHEATING

Slowing the rate of cooling by preheating can give contradictory results as regards improvement in hot-cracking tendency depending on the constitution of the particular weld metal. With intermediate manganese content in association with iron-manganese silicate fluxes, preheating can increase hot-cracking by allowing manganese to remove sulphur from solution so increasing the amount of (FeMn)S of low melting point, which then forms films.

With E217 type high rutile electrodes (with $2MnOSiO_2$ inclusions), preheating will again increase the amount of MnS, but the melting point of the sulphides is likely to be raised to such a point that tendency to hot-crack is not increased, and some reduction is likely due to the lower contraction.

HIGH CURRENT

It is well known that as the current value approaches the maximum tolerated by the electrode hot-cracking tendency increases. Although the retarded cooling obtained by the use of high current values will improve the resistance of E 217 welds, this advantage is more than balanced by the superheating of the weld which results in larger crystals and less grain boundary area to accommodate sulphide.

SILICON AND PHOSPHORUS

In agreement with Reeve, silicon and phosphorus are considered to adversely affect hot-cracking as shown by the following results using different wires and the same batch of flux.

Table II

Effect of	Code	Weld Metal Analyses					Hot Crack Specimen 3" long
		C	Mn	S	P	Si	
Phosphorus	S	0·13	0·55	0·02	0·039	0·15	0
	F	0·125	0·51	0·022	0·072	0·15	1·7 in.
Silicon	Y	0·11	0·50	0·026	0·056	p·135	0
	R	0·10	0·53	0·128	0·042	0·162	2 in.

The variation of silicon and phosphorus content to produce a given change in hot-cracking quality is greater than that of sulphur by a factor sufficiently large to suggest that these elements are not themselves primarily responsible for cracking. It is considered that they act in a secondary manner by increasing the segregation of sulphur as mentioned by Whiteley,[8] who states that at a given manganese content the segregation of carbon, phosphorus and sulphur increases with the total content of sulphur, phosphorus and carbon. Such increased segregation of sulphur is likely to increase the risk of the formation of weak films. The effect of silicon will depend on the manganese content of the weld, but is thought to affect segregation of sulphur in a similar manner

to that of phosphorus. Below 0·1 per cent. silicon little metallic silicon is likely to be present in the weld. With silicon increases to between 0·1 to 0·2 per cent. it is probable that the amount of metallic manganese in the weld, even though total amount is the same, will increase, with consequent improvement in hot cracking. Above these percentages more deleterious effects are usually found if Mn is not similtaneously increased. Phosphorus is more potent than silicon since little loss occurs in welding, whereas silicon can be oxidised under certain conditions.

CARBON

The carbon content can be an important factor in hot-cracking phenomena. Reference to the work of Hall[5] shows that the ductility of steel falls rapidly as the carbon content rises from 0 to 0·1 per cent. which covers the range of welds from the dead soft E.537 to E.217. This fall in ductility is associated with a rapid development of strength which will increase the self-imposed restraint on the weld metal as its carbon content rises.

For example, highly oxidised weld metals are not prone to cracking in practice, but can be readily cracked on the Murex machine where an independent amount of strain can be applied. In other words, in practical applications the dead soft weld metal does not develop enough strain to cause dangerous cracking.

NICKEL

Nickel in amounts as low as 0·5 per cent. in a weld can materially increase hot-cracking, e.g.:

Cracking Length (Ni nil)	*Wire Ni Content%*	*Cracking Length, with Ni*
¼ in.	0·08	½ in.
½ „	E.317 0·32	1¾ „
1 „	0·60	3 „

	Coating Addition Weld Ni per cent.	
Low Mn (0·35) deposit 1 in.	0·5	3 in.
High Mn (0·80) deposit 0 „	1·5	1½ „

Although the complete explanation of the effect of nickel is not understood, it is associated with presence of sulphide films around the grain boundaries of γ. In a single bead these films consist largely of FeS depending on the type of electrode. In, for example, high manganese (E.645 coating) welds a greater quantity of MnS is present. In multi-bead welds these sulphide films are dove grey in colour and respond in etching tests similarly to manganese sulphide. They resist balling up on heat treatment at 1000 deg. C. and in the main appear to be similar to the sulphide films found in pure nickel by Hall.[5] When quenched from 1200 deg. C. some product of indeterminate composition is observed, being dark brownish grey in colour and very powdery on polishing.

It would appear, therefore, that for a given sulphur content in a weld nickel is instrumental in increasing the amount of grain boundary sulphide and consequent cracking.

This work was carried out in the Research Laboratories of Murex Welding Processes Limited, Waltham Cross, Herts.

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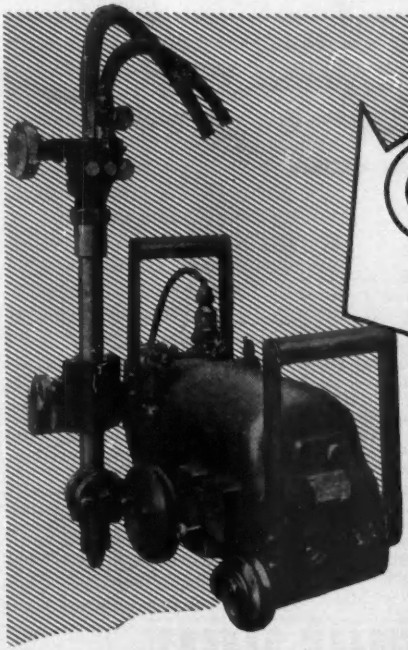

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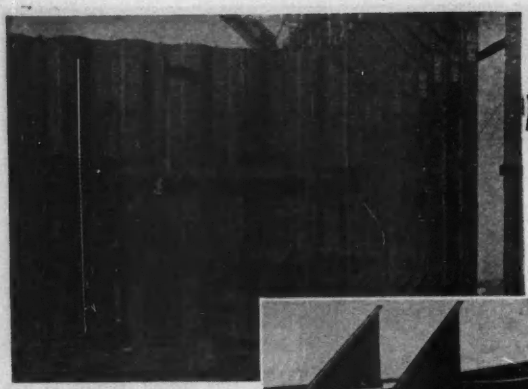

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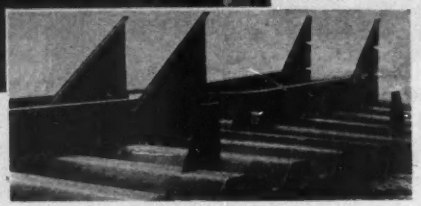

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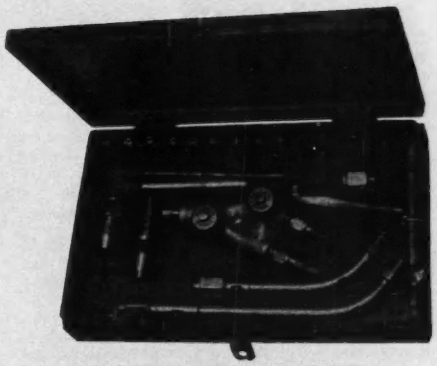

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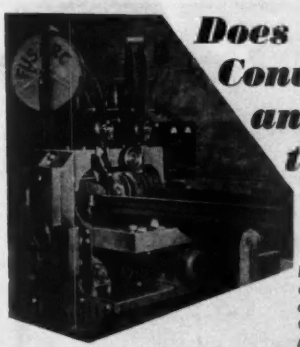

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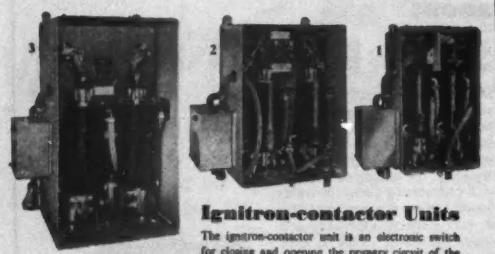

Ignitron-contactor Units

The ignitron-contactor unit is an electronic switch for closing and opening the primary circuit of the welder transformer. Designed for the control of welders of spot, projection and flash-butt type.

RATINGS AT 440 VOLTS

		DUTY CYCLE	3%	10%	25%	50%	75%
FIG	PANEL TYPE	IGNITRONS	kVA	kVA	kVA	kVA	kVA
1	FW242.A4	TWO BK.42	600	361	202	110	73
2	FW224.A7	TWO BK.24	1200	836	475	268	176
3	FW234.A6	TWO BK.34	2400	1976	1100	691	440

NOTE: FW234.A6 can also be used with BK.24 or BK.42 FW224.A7 can also be used with BK.42

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